Methods towards achieving emotional figure animation

Densley, Daniel Joseph

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Methods Towards Achieving Emotional Figure Animation

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Summary

There has been much research into finding ways to simulate the motion of human models in the field of computer graphics. Several methods have been developed using physics and complex mathematics to position and control the motion of the joints. These produce effective and smooth animation, but it is obvious to the viewer that it is generated motion. The problem is that humans know how another human should move, and hence small flaws in motion become very obvious.

This thesis explores methods to solve this problem by taking an approach which integrates emotion into the process of creating animation. Emotion is treated as a major driving force in how an animation is set-up and carried out. To help with the problem of human recognition, the research emphasises the importance of an animator as an integral part of the system. The approach is investigative of methods and techniques which will help in the overall production of the final animation, and also aware of the need for greater understanding of the process of biological movement.

The thesis hypothesis is that this emotional qualification will give much more realistic animation through creation by postures plus emotional state. This approach will mean that animation may be uniquely determined by fewer postures than without emotional simulation, and with a reduced skill requirement for posturing.

Dedication

This thesis is dedicated to the loving memory of my mother and father.

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Chapter 1 Introduction

1.1 Introduction

There has been much research into finding ways to simulate the motion of human models in the field of computer graphics. Several methods have been developed using physics and complex mathematics to position and control the motion of the joints. These produce effective and smooth animation, but it is obvious to the viewer that it is generated motion. The problem is that humans know how another human should move, and hence small flaws in motion become very obvious.

This thesis explores methods to solve this problem by taking an approach which integrates emotion into the process of creating animation. Emotion is treated as a major driving force in how an animation is set-up and carried out. To help with the problem of human recognition, the research emphasises the importance of an animator as an integral part of the system. The approach is investigative of methods and techniques which will help in the overall production of the final animation, and also aware of the need for greater understanding of the process of biological movement.

The thesis hypothesis is that this emotional qualification will give much more realistic animation through creation by postures plus emotional state. This approach will mean that animation may be uniquely determined by fewer postures than without emotional simulation, and with a reduced skill requirement for posturing.

1.2 The Nature of the Problem

1.2.1 The Creation of Natural Movement

The area of figure animation involves a wide range of solutions and a correspondingly large array of problems. Natural movement has been the goal of much work and study and has produced a variety of models for figure motion. The majority of research applies the processes of dynamics and kinematics to great effect, but it is evident that more work is needed if natural movement is to be achieved. Solutions using dynamics take the human figure as a series of connected masses to which forces must be applied to make them move [2, 4, 8]. This can produce very effective results for certain situations, such as gymnastics, but it fails to produce believable models for basic tasks like running or walking. There are two types of kinematics, direct and inverse [6, 9, 10]. Direct kinematics is the process of positioning the figure by setting joints implicitly. Inverse kinematics takes the approach that, given certain positional criteria such as the placement of the hand, other joint angles can be calculated from constraint values. These techniques are discussed in more detail in the chapter Background Information.

Solutions to the problems of natural movement are restricted by current theories and understanding in many scientific areas. Psychology, physiology and physics can all play a part. Why do people move in the way they do, and what controls how they act? The answers are not clear cut and some theories and understanding of the issues involved are underdeveloped. Thus the difficulties presented by the problem of producing natural animation are in two main areas. What can be done based on current understanding and what can be done to minimise any shortcomings? An animation system which tries to solve these problem must address these areas. Current systems do not consider emotional input to be an important part of natural movement. It is only relatively recently that the inclusion of some emotional input into the process has been considered and used [9, 12, 13, 33]. In many cases emotion is being put into existing systems as an addition rather than an integral part of the process. If emotion is to be used effectively, I believe a good awareness of current psychological understanding and also of expressive body movement is required. Emotion should be made an integral part of the entire animation process. This approach presents its own problems as the basis is in psychological ideas which are not scientific fact. It is important that this is taken into account in the design of a system and that other methods to minimise any problems are investigated. Human movement is very subtle and study in this area has only identified a small area of the tremendous complexities of motion that can occur [42].

1.3 Application Areas

There is a wide application area for an emotionally based natural animation system. The field of animation is continually expanding and progressing and there is a constant need for more tools which help speed up and improve the animation process. From the entertainment industry to training and research, the area in which computer graphics play an important role is expanding.

The largest area of use for this sort of animation system would be the entertainment industry. This is divided into several areas which have their own specific requirements and needs. Most obviously there are the film and television industries. There is large and growing use of computer animation in this area. Computer graphics are used in most blockbuster films and some, such as Toy Story, are created entirely using computers. There is a need for fast and easy to use animation systems for a variety of uses. Natural movement of computer generated human figures, or animals, and animated objects which display human characteristics, relies heavily on the skills of the animator. This can be time consuming and hence very costly. Animation is a process which takes a large amount of time, so techniques which can cut the time without a detrimental effect on the results are highly desirable.

Further to the large film and television industries is the computer games and multimedia industry. The current trend in games and the computers or consoles on which they are produced is three dimensional graphics. It is an industry which is built on cutting edge technology and techniques. As games move from the traditional two dimensions into three, older animation techniques need to be updated. Currently the top development companies use motion capture techniques to produce fluid and realistic figure animation. However motion capture equipment is very expensive to buy, so most software companies do not have access to the technology. While the results are useful for pre-rendered introduction sequences, the application in-game is difficult and restrictive. An animation system is more flexible for interactive control of a character. The movement can be more varied and reactive to player commands, giving a greater feeling of control to the user.

In television and training there is growing use of the virtual presenter, a computer generated character which introduces a programme or presentation. Recently the BBC spent a large amount of money on a character called Catz. The on screen image of the head of a cat was controlled by an actor in motion capture equipment. The actor's head and facial movement was translated to the model of the cat head and superimposed onto the normal television broadcast. The results were impressive but also very expensive. Other current techniques use pre-rendered sequences which often look robotic and lack personality. The use of an efficient human figure animation system would be more flexible and less costly.

A definable animation system, where the user has control over the emotional interaction, could be useful in expanding the theories on which it is based. By exploring the possibilities presented by the system, psychologists could test and develop their own theories in emotion / body language interaction. As psychological theories of emotion and body language are still very much in development, an animation system to test theories could be a valuable tool.

Chapter 2 Background Information

2.1 Computer Animation

This chapter looks at previous research in associated areas. The extent of background research covers a wide area. This first section looks at work in the general area of computer animation, concentrating on research into methods of closing the gap between the scientist and the artist. The second section is concerned with figure animation. It looks at the development of current techniques in the areas of kinematics, dynamics and other less common approaches. The third section examines approaches to the use of emotional models in computer systems. This covers behavioural systems, facial animation and figure animation.

It is important, before developing an animation system, to look at the current approaches to the problems associated with computers as a tool, and to examine techniques for getting the most from the medium. Computers are intrinsically scientific tools, designed to crunch numbers and solve largely numeric problems. As computers have become more powerful their use has been expanded to a large area of application, including computer graphics and animation. However there have always been problems in relation to the creative processes and applications using computers. For an emotional animation system where the human and creative input is valued this problem takes greater importance.

A significant paper to address and quantify these problems was 'A Survey of Computer Animation' by Xavier Pueyo and Daniela Tost in 1988 [30]. The paper clarified what computer animation was, examined its aspects and related problems and presented some solutions. It is an important study as it recognises the problems of motion control, particularly applied to human figure animation, and the problems of user interface restrictions. Another important study in 1987 was the paper 'Principles of Traditional Animation Applied to 3D Computer Animation' by John Lasseter [29]. This study focused more on the creativity and techniques of traditional animation. John Lasseter has often been a campaigner and supporter of greater awareness of creativity in computer animation. The paper tries to show how traditional methods used in animation for years can also be applied effectively in computer animation. The animation produced by his company Pixar, such as Luxo Jr, bears testament to this. The use of traditional animation techniques, such as anticipation, exaggeration, timing and composition can also have great use when applied specifically to emotional animation.

Research specifically into the tools needed for creativity in human figure animation has been done by Tom Calvert et al. [31] and taken further by Armin Bruderlin [32]. Calvert was primarily concerned with choreography and dance movement, and hence composition. Bruderlin, who had worked with Calvert on previous work, took the theories further to general figure animation and interaction with environments. The work by both focused on the use of hierarchical definition of the posturing and animation process.

2.2 Previous Figure Animation Work

This section examines the development of current theories and techniques in figure animation. Starting with early research into kinematics and dynamics it looks at the evolution of these and other methods towards the techniques of the present. It also examines the milestones in development where the approaches of the time are presented collectively as current state of the art.

2.2.1 Collective Studies

In 1982 the first significant theories of human figure control methods were put forward in Computer Graphics and Applications under the title 'Modelling the Human Body for Animation' [56]. While the emphasis of the title was on modelling aspects, many of the papers were an examination of motion control methods for the animation of human figures. These included early studies of goal-directed kinematics and parametric interpolation. In 1987 another collection of current research was put together under the more appropriate title 'Articulated Figure Animation' [1]. This contained many of the important papers that formed the basis of further study in the areas of kinematics, dynamics and the use of constraints to animate a human figure.

Following on from these early studies the theories have been developed and extended. Books edited and written by the Daniel Thalmann and Nadia Magnenat-Thalmann and proceedings of the Computer Animation conferences have chronicled the development of these methods [8, 11, 38, 39]. Another major collection of theories was the book 'Making Them Move' published in 1991 [36]. Again the theories centred around the uses of dynamics and kinematics. In 1993 the book 'Simulating Humans: Computer Graphics Animation and Control' by Norman Badler et al. put together the growth of the Jack system developed in the University of Pennsylvania [37]. The Jack system has been developed using multiple techniques dependent on application and motion, with an emphasis on engineering and design applications rather than creative animation.

2.2.2 Kinematics

There are two basic types of kinematics, direct, or forward kinematics and inverse kinematics. With direct kinematics the posturing of the figure is done through explicit joint definition. Inverse kinematic is more complex but has greater uses, here the joints are set according to constraints and positional criteria. The difference between direct and inverse kinematics can be seen by considering the positioning of the arm. With direct kinematics first the shoulder joint must be positioned, then the elbow and finally the wrist. With inverse kinematics the hand is positioned in the required posture and the joint values of the rest of the arm are calculated using constraint information.

The development of the more complex inverse kinematic techniques has been largely led by Norman Badler [3, 7], Daniel Thalmann and Nadia Magnenat-Thalmann [8, 10, 11]. Combined direct and inverse kinematic methods have also been used by Ronan Boulic and Daniel Thalmann [9]. Kinematic processes can produce good but often robot like results. Kinematics is especially useful in posing of an articulated figure.

2.2.3 Dynamics

Where kinematics looks at positions of key body components, dynamics takes the approach of forces and masses. The figure is broken down into masses and muscles are simulated as springs and dampers. Thus the motion of a joint is due to forces applied and modified by joint characteristics.

Significant early research in this area was carried out by Wilhelms and Barsky in 1985 [16] and in 1987 in the Articulated Figure Animation collective study by Wilhelms with the paper 'Using Dynamic Analysis for Realistic Animation of Articulated Bodies' [4]. Also in the same study was a paper by Armstrong, Green and Lake in which the dynamics of the figure were simplified to produce near real-time dynamic control [5]. From this period onward dynamics has played a major part in the development of computer calculated human figure animation. In many cases dynamics has been combined successfully with kinematic methods, such as the system developed by D.Thalmann [8, 9, 11]. It has also been used successfully in generating movement of a specific type, such as gymnastic models and swinging and cycling models [14, 15, 17, 18].

While dynamic solutions to human figure movement are well suited to certain types of motion, such as gymnastics, the results for general movement are better handled by kinematic or mixed methods. When applied to emotional animation the connections with tension are interesting but animator interaction is not so intuitive as in other methods.

2.2.4 Other Methods

While the majority of the work in human figure animation is in the areas of kinematics and dynamics there are other methods for motion control. Optimal Control methods, presented by Brotman and Netravali, are specific to motion interpolation [20]. The approach is to find connections between interpolated parameters and hence produce more natural motion. Spacetime constraint methods, where the motion is defined in terms of constraint information but not specifically how to perform the action, have been studied in several papers [21, 23, 24]. The method is closely linked to dynamic techniques in its use of physical information to generate movement. Other methods include the use of sensor-actuator networks [22] and motion signal processing [25]

2.3 Previous Emotional Work

Within the context of computer animation and computer models there are three areas of emotional research: The behavioural based work, facial animation and figure animation. The behavioural work is concerned mainly with modelling human interaction with the environment and other humans. The area of facial animation has been the focus of most emotional animation research, with little previous work in the figure animation field.

2.3.1 Behaviour Based Work

Behaviour based research in the area of emotion and simulation of human interaction is an interesting and expanding field. The aim is to simulate part of the human mind to be used in given situations while reacting appropriately. It has strong connections in the field of artificial intelligence. Some of the most significant work in this area has been by Scott Reilley [28], who created a good psychological model for the mind of a child which could interact in a playground environment. More recent work of interest is the AIR model developed by Sato and Miyasato [34]. Here simulated humans interact on a basic level within an environment. A particular point of interest is the use of two emotional models, one to represent the internal emotion felt and one to represent the emotion expressed by the agent. The emotion expressed by other agents affects the internal felt emotion, which is then interpreted and filtered to affect the external expressed emotion. This is closely associated with masking of emotions, something explored by Daldegan in her facial animation work [26].

2.3.2 Facial Animation

When considering emotional animation the more obvious area of expression is the face. Hence the majority of emotional figure animation has been done in this area. For this the facial area has to be modelled taking into account bone structure, muscles and skin properties. These aspects have been the subject of research by Patel [27] and Thalmann / Magnenat-Thalmann [8, 11]. Emotional facial animation, with more emphasis on the underlying emotional model has also been done by Daldegan [26]. There has also been work on facial movement in connection with related hand and arm gestures by Pelachaud and Badler et al. [19].

2.3.3 Figure Animation

Research in figure animation has concentrated on the creation of natural motion. Where emotion has been applied it has generally been in the more obvious area of facial animation. There has been some research in this field however. The 'Generation of Human Motion with Emotion' work done by Unuma and Takeuchi [12, 13], uses data from a human subject and attempts to extract the emotional elements using Fourier transforms. Motion capture data is taken of a human walking normally, and then walking expressing an emotion such as joy. The data is manipulated using Fourier transforms in a way that the emotional element is quantified. It can then be added or taken away from the standard motion to produce various levels of emotional expression. The technique has produced impressive, but restrictive, results. Similar work to this technique has also been done by Amaya, Bruderlin and Calvert, presented at Graphics Interface '96 entitled 'Emotion from Motion' [33]. The approach relies on capture of human subjects performing actions with various emotions, such as anger, sadness and neutrality. Then for each emotion an emotional transform is calculated which represents the "difference" between the neutral and emotional movement. The transform is then applied to a new neutral movement. The main difference between this work and that done by Unuma and Takeuchi is the method for extraction of the emotional transform, and the criteria it is based upon. Both methods rely on the definition of a neutral emotion, the existence of which is debatable.

Other research in this area has been carried out as part of the Thalmann / Magnenat-Thalmann model, where behavioural elements, such as emotion and character, are added to motion generated by kinematic and dynamic techniques [9].

Chapter 3 Methods and Design Issues

3.1 Goals of the System

The main goal of my research was to create a system for producing natural animation of the human figure. The Dynamic Emotional Gesture Animation System, DEGAS, is the result. While previous work has aimed to achieve this same goal the approaches have been wide and varied, and the results, while impressive, still leave room for improvement. There is a noticeable difference between animation which has been calculated by computer and that which has been motion captured. The approach of DEGAS is different in two main areas. Firstly the system is based around emotion and its associated body movement and posturing. It is an objective that emotion should play an integral part in how an animation is set up and how it is carried out. Secondly there is a tendency in the field to try and automate as much as possible. DEGAS goes against this trend in aiming actively to encourage the use of one of the most potent tools available, the animator.

3.1.1 Emotional is Natural

In the search for natural movement, emotion should be considered a necessity. When describing movement it is usual for a person to use emotions to relate what they see. It is common to think of movements by relating to words which also describe an emotional state, such as joy or arrogance. Although we may try to hide it, the way we act and move says a lot about our internal mental state. It is part of being human and thus should be considered in an animation system which tries to help create natural movement. With this in mind, it is the main objective of DEGAS that emotion plays a part in all areas of the animation process, from the set up of a motion to the way in which it is carried out.

3.1.2 A Tool for an Animator

The best test for the quality of an animation is to watch it. As people we recognise when an animation looks right or wrong because we see humans move all the time. This is one of the major obstacles of DEGAS, or any other animation system which tries to produce natural movement. If the animation system was restricted to non-human models then there would be less of a problem. When watching an animation involving animate objects, as opposed to humans, an audience does not know instinctively how they should move. Hence the mind will accept imperfections in the motions as long as they fit within the boundaries of what is expected. However with human animation the slightest flaws are noticed. This can destroy some of the illusion of what an animator is trying to create. This effect is noticeable in the film Toy Story. One of the goals of the film was to produce an animation where the audience would forget that what they are viewing is computer generated and see the story being told behind it. It was one of the reasons for using toys as the main characters. When a toy is being animated the viewer will accept what they are shown if the toy moves close to how the viewer imagines it would. Yet when there are humans in the story it is noticeable that they do not move naturally. It is for these reasons that DEGAS aims to assist an animator, and recognise their skills as an important available tool.

A DEGAS objective is that it should provide help for an animator to produce what they want without restrictions. Thus full control at all levels should be provided where possible. One of the most important things about any creative process is that, given the same instructions and the tools to carry them out, the result from each person should be different. It is a fundamental principle of artistic creation. Automation takes away from the creative process. DEGAS is aimed to be a creative tool to stimulate rather than stifle the artist. Details, such as the emotional state, are to be represented using common terms and clearly understandable models. The animation process should be familiar and easy to use, yet powerful enough to allow the animator to achieve what they want.

3.1.3 The Importance of Key Frames

Based on the emotional ideas and consideration for the animator, DEGAS is a key frame animation system. The trend in the field is away from key frame animation towards more autonomous systems. Autonomy is better for some applications, for example complex spatial navigation, but there are good design foundations behind key frame use in the area of emotional animation. The key application areas in the entertainment industry are also well suited to this sort of approach, enabling animators to create characters with distinctiveness and personality.

Studies of body language and emotional expression show that the posturing is very important in the indication of the emotional state of a figure [43]. The important postures of an animation will be the key frames. So it is sensible to approach the problem by making a key frame animation system. In this way the animator can control these major aspects of the animation, and emotional interaction in the posturing process can be applied.

Key frame animation is also how traditional animators have worked for years. Skills and expertise have been developed in this area which would be useful to exploit in this sort of application. Key frames provide a familiar working environment for an animator and allows a large degree of control over the final animation. Traditional animation techniques can also be well adapted to a key frame animation system.

3.1.4 Real-time Implications

When producing animation, it is a great advantage to see the results of what you are doing as quickly as possible. Traditionally, animators have had to rely on instinct and experience in creating what they are trying to achieve. A hand drawn animation requires a great deal of work before any result can be analysed. Several frames must be drawn and put together which takes a large amount of time. Once an animation is produced it is then difficult to alter in order to address any problem. The use of a computer provides great opportunities to overcome these problems. It is a goal of DEGAS to be a real-time application, so that an animator may preview an animation and, most importantly, make adjustments to it with little trouble or extra time used. This enables the animator to analyse their work and reduces production time. It is also an aim of DEGAS that adjustments an animator may make to a posture be realised as the change is made. This again enables the animator to see immediately what effect any changes that are made have.

3.1.5 A Need for a Definable Expandable System

The application area of emotional animation encompasses many grey areas. Areas in which scientific opinion is divided and unclear. The study of emotions themselves is complex and requires more development. It is often difficult to define terms used in an acceptable way, such that it is obvious what is meant. For these reasons it has been an intention to make DEGAS a definable expandable system. A definable system allows the user to control as much of the use and interaction as possible. An expandable system will permit future expansion and development. These characteristics also allow for expansion and further development of the theories behind the system. By putting the theories into practice they are put to a practical test, which can help in their own progress.

A consequence of this is that DEGAS can be a more useful tool. The areas of application open up with the possibilities created by this approach. By allowing greater control of the interaction there arises the possibility of using non-human figures. If a model is designed within the specifications of the system then it can be used just as easily as a human figure. The definition control means that important differences between other models and that of human models may be handled in a sensible and intuitive way. For example, a animal model may have a joint which is used in a different or more restrictive way than the relevant joint in the human model. This joint can be adjusted so that the controls are more sensitive to it's limited movement. The interaction can also be defined in a way such that the special properties of the joint are used accordingly. The ability to define interaction differently for each model provides a method for giving models a distinct personality. The definitions can also be kept separate from the standard model geometry, so a different personality can be used with the same model.

The design of the emotional interaction and animation process of DEGAS takes these ideas into account. The aim is to produce a system which allows the user to define the interaction as far as possible whilst making the system easy and intuitive to use.

3.2 Exploring the Use of Traditional Animation Techniques

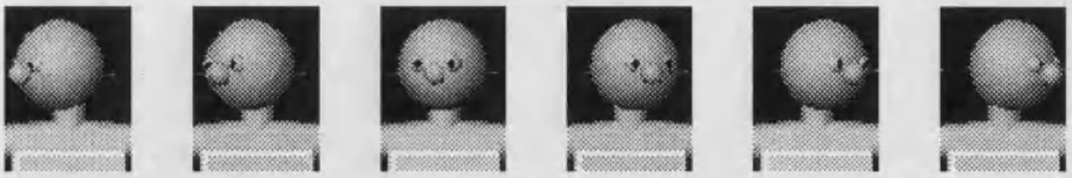
The exploration of traditional animation techniques is an important part of DEGAS. Traditional animators have special techniques to help them achieve their desired effects. These processes can also be very useful in modern animation systems. The use of timing, anticipation, exaggeration and secondary action have been recognised as helpful in producing realistic animation [29]. There are also other aspects of traditional animation and fine art techniques which could be applied, dependent on application, such as the use of colour and method of composition. DEGAS aims to explore the possibilities and techniques in this area. However DEGAS does assume familiarity with the principles of the various techniques. It is not intended that DEGAS should implement the methods autonomously, rather that they should be readily available for use and easily implemented into an animation.

3.2.1 Timing

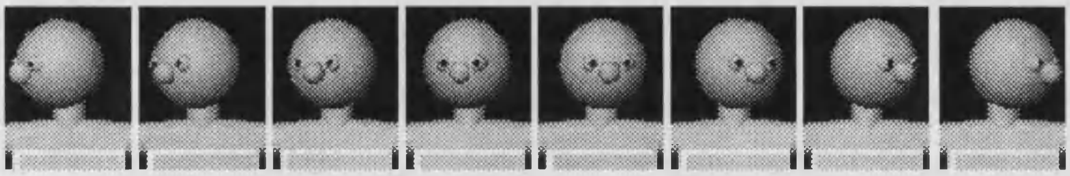
The use of timing is fundamental to an emotional animation system. How quickly or slowly a movement is carried out can greatly affect the expression produced by the animation. How someone moves shows a great deal about how they are feeling. Timing also gives information about the weight of what is moving. By using appropriate adjustments to the timing of a motion an animator can give the same object a different feel and character. DEGAS aims to provide the animator with comprehensive but simple-to-use control over this important aspect of animation.

To illustrate the variety of effects timing can produce, Thomas and Johnson [55] used the turning of a character's head from looking over one shoulder to looking over the other. The visual effect was categorised on the number of in-between frames used. This can be seen in figure 3.1. Example (i) has no in-betweens which represents the character being hit by a very large force. The example (ii) has four in-betweens, here the character is moving quickly and crisply. Finally example (iii) has six in-betweens, the character has seen a sports car he has always wanted. These are just three of the eight classifications given by Thomas and Johnson, but they demonstrate how effective and important the use of timing is.

Example (i)



Example (ii)

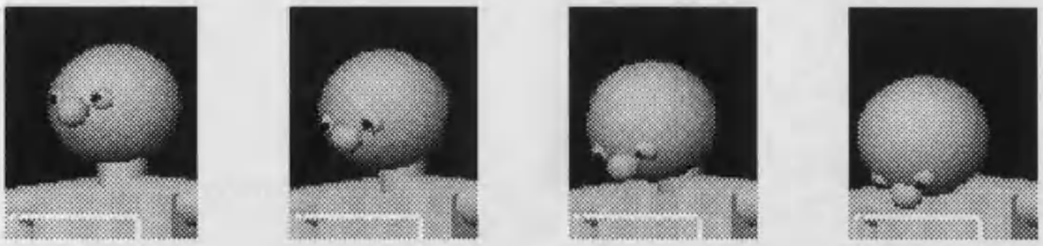


Example (iii)

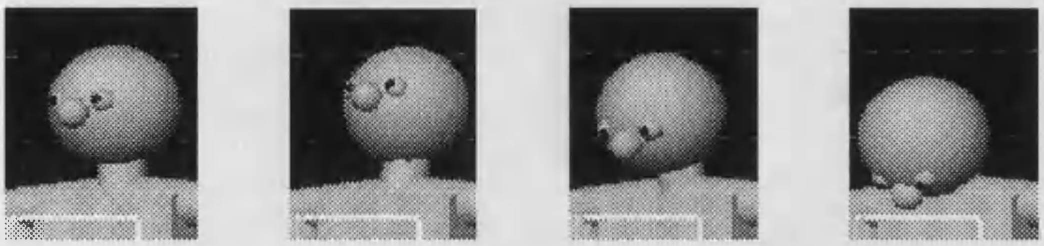
Figure 3.1 Examples of the Effect of Timing

3.2.2 Anticipation

Anticipation is the technique of setting up a motion which is about to be performed. This helps the viewer in predicting what is to come and makes the resulting animation more realistic. This technique can be implemented automatically in a key frame animation system by looking forward to the next frame and producing an animation which sets up the anticipation motion. In figure 3.2 there are two sequences of an animation. In example (i) the head makes a simple nod action. In example (ii) the action of slightly raising the head sets up the nod motion and as a consequence it looks more natural. This is discussed in further detail in the chapter on Animation Implementation.



Example (i)

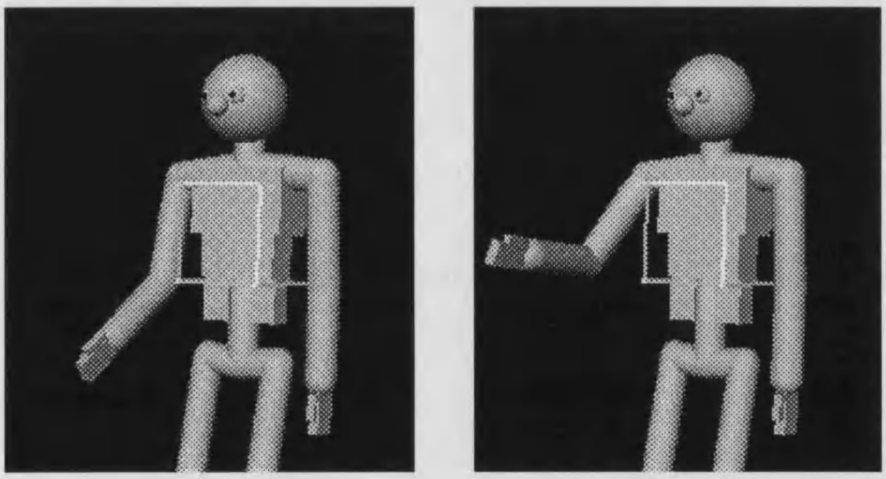


Example (ii)

Figure 3.2 Examples of the Effect of Anticipation

3.2.3 Exaggeration

Exaggeration of movement is often used by an animator to help the viewer see what is being expressed more clearly. It is also commonly used by people in real life for the same purpose. When a person wants to make their feelings clear to another, their movements can become exaggerated to draw attention to what they are trying to express and to stress the importance. This is a significant method of expression and as such should be readily achievable in an emotional animation system.



Picture (i) Picture (ii)

Figure 3.3 Examples of the Effect of Exaggeration

The example in figure 3.3 shows how exaggeration can change the mood or feeling expressed. In picture (I) the figure holds out his hand as a greeting. In picture (ii) the posture is exaggerated so that the hand is put further forward. This gives the effect of friendliness and welcoming, the first picture looks more staid by comparison.

3.2.4 Secondary Action

Secondary action is a motion which is a consequence of a primary one. Balancing is a good example of this. If a person leans forward then to avoid falling over they balance themselves by adjusting their stance. The stance adjustment is the secondary motion as a consequence of leaning forward, the primary motion. It is an aim of DEGAS to provide the means to easily implement secondary motion in the posturing and animation systems.

Figure 3.4 shows an example of secondary action. Using the posture of a hand outstretched, as in the exaggeration example, the left hand of the figure is moved back as a secondary action. The origin of shaking hands as a gesture of welcome or friendship is thought to be based on showing that you have no weapon in your hand, you come in peace. The action of moving the left hand back further reinforces this notion, as it is a non-aggressive movement.

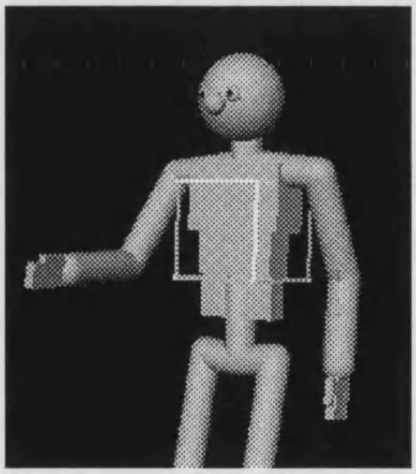


Figure 3.4 An Example of the Effect of Secondary Action

3.2.5 Composition

Another technique employed by artists is the use of composition. It is the key to a good work of art where the eyes of the viewer are controlled by the artist. The eye is led around the picture so that it tells the story that the artist intended. This technique is also used in animation. The eyes and mind of the viewer are led around the screen so that the best effect of the animation comes through. In this way the animator can direct the movement and concentrate on the area of interest. It is important for a natural animation to flow freely, and this technique helps achieve that. Common examples of composition are framing and dramatic use of the view point. If a scene is displayed, the viewer's eye should not wander off the edge of the screen, or want to see more than is being shown to them. A view can be framed by ensuring all that the viewer wants to see is available, and by keeping the attention of the viewer within set boundaries. Dramatic use of the viewpoint can also help greatly with emotional animation. By simply lowering the view point and looking up to a character displayed in an animation it is possible to change the feeling of the interaction with the viewer. The impression of a more dominating and imposing figure can be powerful in instilling a feeling of fear. Expression of emotion on the screen has much to do with the emotion felt by the viewer themselves.

Composition is also closely connected with the use of timing, anticipation, exaggeration and secondary action. How these other techniques are used has a great effect on how the viewer is lead through an animation. While these techniques can be examined individually, to be used to best effect they must work together towards what the animation is trying to achieve.

3.3 Emotion

Psychological theories have major implications with respect to design issues. This section begins with an examination of internal emotions based on both the current psychological theories and their foundation. The following section then discuss the external bodily expression of emotion and how this is linked to the internal emotions. Finally the issues of perception in relation to body language and emotional expression are examined. Throughout, the design implications of these theories are related to the implementation in an emotional animation system.

The basis of this research is that emotion is a driving force and main component of movement and posturing. Emotion is considered to play a direct role in how an animation should be set up and carried out. It is necessary to examine the very nature of emotion and its physiological effects in order to justify this approach. It is also important to explore current psychological theory in order to assess how this may influence the design of an emotional animation system.

3.3.1 What is Emotion?

emotion *n.* a moving of the feelings; agitation of mind; any of the various phenomena of the mind, such as anger, joy, fear or sorrow, associated also with physical symptoms; feeling as distinguished from cognition and will (*philos*). [55].

It is important when looking at psychological theories of emotion to take into account the common interpretation of emotion. Emotions are felt and experienced by all people. When describing how they feel, people will often refer to more common and recognizable emotions that are familiar to us all. They will also describe physical symptoms associated with the mental feelings. In designing a system to be used by animators care must be taken to ensure they will understand and be able to use an emotional model which is put before them.

Research into emotion is not as well developed as other areas of psychology. Theories are therefore varied in their approach and nature. There have been studies by anthropologists, sociologists, and neurophysiologists as well as medical and psychological approaches. It is only recently that these theories have been coming together to form a more cohesive understanding of emotion. Psychologists now consider emotions a complex combination of both mental and physical changes. The interaction of these changes and the way in which emotions work is a matter of great debate. When examining the theories within the context of an animation system it is important to look at the connections made between the mental and physical responses. An emotional animation system will have to simulate this link. The emotional state of the figure provided by the animator should adjust the posture and control the animation of the model.

One of the earliest explanations of emotional response was the James-Lange Theory which maintains that the psychological experience we call emotion follows the experience of bodily responses to a stimulus [40]. We do not cry because we are sad, we feel sad because we cry. The more common interpretation was the opposite of this, that physical response followed the mental. This theory was held up by tests and examples. Though now it is no longer supported it played an important part in further development. It has been shown that there is some truth in the theory through biological studies of the face. Through this it is theoretically possible to cheer yourself up by smiling. The disturbance in blood flow and muscle movements contribute to give the impression of joy and the full emotion can result.

The Cannon-Bard Theory followed, which attacked the James-Lange Theory, and suggested that psychological experience and bodily response to a stimulus occur simultaneously [40]. The experience of the emotion in the mind and in the body occur at the same time, they are both a result of the emotional stimulus. This theory maintained that there was no connection or interaction between the mental and physical responses.

Figure 3.5 shows how the initial theories of emotion, the common interpretation, the James-Lange theory and the Cannon-Bard theory relate to each other. The base components of emotional stimulus, mental and emotional response feature in each theory.

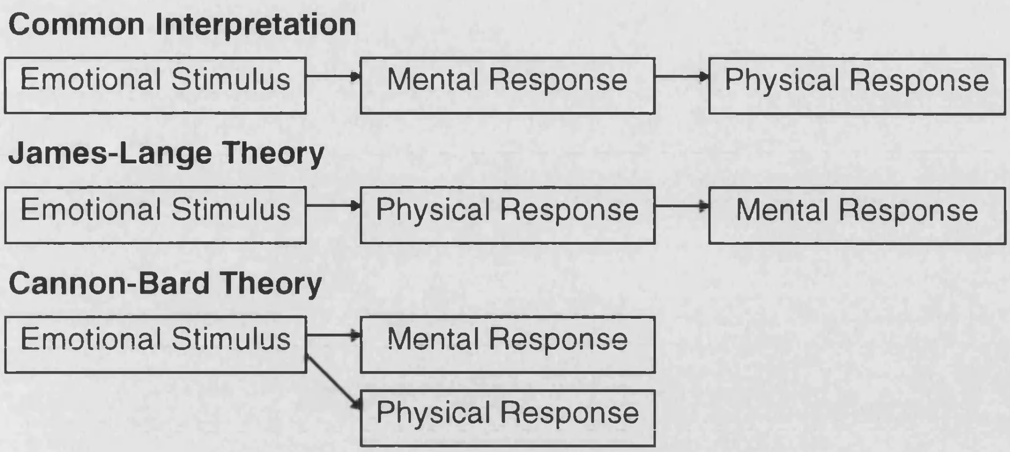


Figure 3.5 The Early Emotional Theories

The Cannon-Bard and James-Lange theories have led to the more recent combination theories which put forward the idea that the mental and the physical responses are inter-linked, both affecting each other [40].

A simplified model of the combination theories contains seven components. First there is the subjective experience, the emotional stimulus. There follows the internal bodily responses of the autonomic nervous system and the mental response to the stimulus. These are evaluated in a cognitive appraisal which leads to the expression of the emotion and perceived arousal. These then combine to produce the experienced emotion, see figure 3.6.

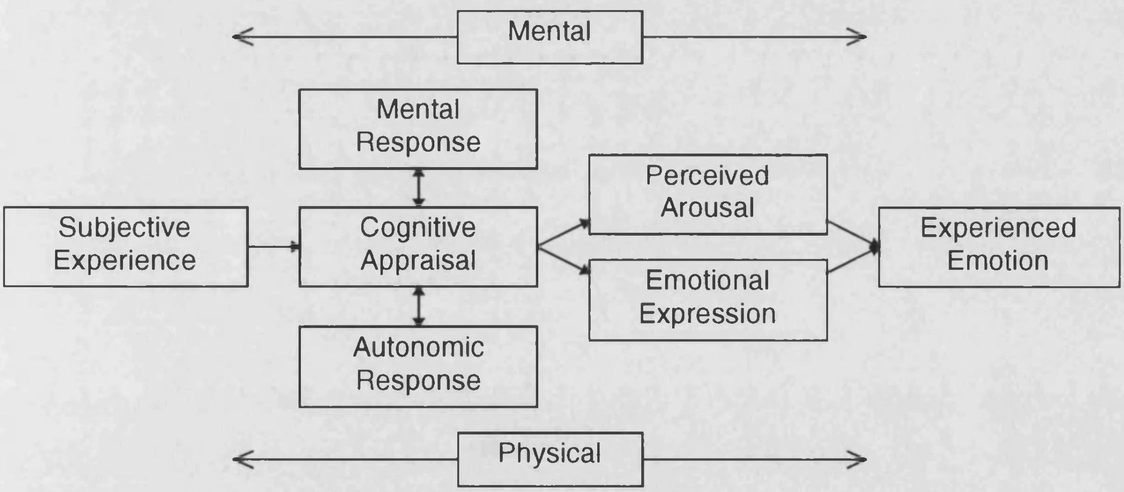


Figure 3.6 The Combination Theory

This theory takes into account the basis of both the James-Lange and Cannon-Bard theories. It also allows for expansion in the study of the cognitive appraisal process. Appraisal was originally put forward by M Arnold and J Gasson [40] who proposed that the emotional experience is as a result of appraising events. From this it is asserted that if the appraisal is known then the resulting emotion can be deduced, and also that if the emotion is known then the appraisals can be described. This is the basis of modern psychological emotion theory.

When looking at these theories in the context of an animation system it is clear that the physical response is very important. It is this which will determine how an animation is affected. While the theories may differ in how the physical and mental interaction occurs what is clear throughout is that emotions or emotional stimuli affect the way we are, and how we act. All theories take into account a definite physical response to emotional stimulus, leading to the conclusion that emotion should affect movement and stance in an emotional animation system. As a consequence of this it is apparent that some degree of emotional simulation is needed in order to produce natural animation of a human figure.

Further examination of the cognitive appraisal process can provide useful information which may affect design issues of an animation system. The interaction of the autonomic response and mental arousal, and hence the resulting emotional expression, can depend on the current emotional state of a person and also how the current state was reached. Emotions are rarely distinct, a new emotion does not simply replace one already being experienced. This would need to be taken into account in an animation system involving a dynamic emotional state. Using a history of emotional states an update of the current state can be determined. The intensity and type of an previous emotion can be used to determine how long it remains in the emotional history. As time passes a previous emotional state should decay in intensity and thus how much it affects the current state.

3.3.2 Emotional Models

It is important to examine carefully how emotional models are represented by psychologists before deciding on a model suitable for use in an animation system. The model has to be flexible and understandable for the requirements of the animator.

Emotion is a complicated issue psychologically. There is no one accepted model that could readily be used in a computer representation. There are, however, several similar models which define a number of basic emotions and categorise other more complex emotions as combinations of the basic ones. The use of emotional combination is important, as although we often try to categorise our emotional state as a single emotion we actually tend to experience emotions in clusters [42]. Carroll Izard proposed a basic set of ten emotions, see figure 3.7 [41]. Under his system a complex emotion such as love can be mode from a blend of Joy and Interest/Excitement.

Robert Plutchik devised an Emotion Wheel, see figure 3.8 [48]. In this representation complex emotions are again made up of combinations or blends of the eight basic emotions. In the Emotion Wheel however the eight basic emotions are arranged in a circle of opposites. For Joy there is Sadness, for Acceptance, Disgust and so on. Secondary emotions are defined by blends of adjacent basic emotions on the wheel, these are shown in the diagram. This creates a balance in the model. People vary in their interpretation of individual emotion descriptions, such as ‘disgust’. If instead they are given a pair which define a range, such as ‘acceptance - disgust’, then the ambiguity is reduced. This then makes it easier to define more complex emotions which is an important benefit of the model.

Anger	Guilt
Contempt	Interest/Excitement
Disgust	Joy
Distress	Shame
Fear	Surprise

Figure 3.7 The Ten Emotion Model of Carroll Izard

Figure 3.8 The Plutchik Emotion Wheel

The approach in which complex emotions are built from blends of basic emotions is useful if we wish to apply the model to a computer simulation. The elements of one emotion can be combined with the elements of another to give that of the complex emotion. For instance someone who is frightened may want to protect themselves from what is scaring them. Someone who is surprised would be taken back by the thing that is surprising them.

Combining these would give a rapid motion away from the object of fear and surprise, with movement to increase protection of vulnerable areas. This gives the movement of someone who is surprised by something frightening.

Emotional models used in behavioural research such as that by Reilley [28] and Sato and Miyasato [34] have often been geared toward the environment being simulated. There are some points of interest however, such as the use of an internal and external model of emotion, for that felt and that expressed.

3.4 Bodily Communication and Body Language

"If the lips are silent he chatters with his fingertips; betrayal oozes out of every pore", Freud.

It has been seen from the psychological theories that there is a link between emotion and physiological response. It is necessary to examine this relationship in order to justify the validity of its use in an animation system, and also explore how to it may be implemented.

Body language has been the subject of much attention but it is a highly complex area of study. It is full of subtleties of movement and tremendous complexity. There is a problem in description of body language caused by the limits of verbal communication. As a consequence of this only a small amount of the possible movements have been identified for study. Collier expressed the problem by stating "any description of body movements occurring can only hint at the tremendous complexity of what is actually taking place." [42]. It is important to realise these problems in designing an animation system. There are elements to body movement and language that are, with current understanding, not quantifiable.

3.4.1 The Emotional Connection

Expression of emotions through facial movement, gestures or how an action is carried out is a natural process. It is deeply subconscious such that attempting to hide true feelings is often difficult, especially if the emotion is strong. Expression is part of what we are and as such attempting to synthesise natural-looking movement requires taking into account emotional aspects. [42].

When looking at the area of emotional expression most research has been in the more obvious area of facial expression. From early studies by Darwin [57] up until the 80's body movement as a way of expressing emotion was considered secondary to the facial aspects. In studies Ekman found that people could more easily distinguish emotional expression from pictures of the face than from pictures of the human figure [43]. Further it was shown that people found it easier to distinguish the emotional intensity, or an emotional range, from the figure rather than recognising the actual emotional state. However, these results have been modified by further study. The problem lies in several areas. Emotional body language is subtle in its nature. A lot of what we see we react to but the process can be subconscious in much the same way as the expression of the emotion is. Asking people to recognise specific emotions from still pictures is not the natural process by which we normally work. Further to this there is the problem of separation of what is emotional expression and what is normal body movements. An action or general posture does not always express emotion, however the way it is carried out does. Ekman's studies used still pictures with no visible faces as this would have affected the results. It is difficult for people to recognise emotions simply from a still picture. Appraisal of body language is a gradual process with new information from motion continually being assessed for significance.

Ekman distinguished four types of body movement, emblems, body manipulators, illustrators and emotional expressions [42]. Emblems define the set of culturally specific symbolic actions, such as waving and hand signalling. Body manipulators are where one part of the body manipulates another. Usual examples of this are head scratching or licking of the lips. These are habitual responses. Illustrators are used in conjunction with speech to re-enforce or expound an idea or concept, such as pointing or motioning toward the object of discussion. Emotional expressions are motions or gestures specifically linked to emotions, which are the ones with which we are concerned here. Ekman asserts that these are largely innate, which is an important point discussed in a later section.

The problem of separating emotional expression from non-emotional movement is important in its implications for design of an emotional animation system. Cultural specific movement can be allowed for but is not necessarily inherent to the system. This makes the system more universal and flexible in its nature. An animator should have the ability to produce an animation for a target audience. The system should not introduce gestures which mean different things depending on your culture as this restricts the audience it is applicable for. For instance the gesture of tapping your finger on your nose can mean many things depending where you are from. In the British Isles it's used to mean 'Mind your own business', whereas in France it is used to warn that someone is nosey, and in Sicily to praise someone's alertness.

3.4.2 What is Learned and What is Innate?

A general animation system - one which does not try to reproduce culturally specific gestures - is a logical approach. However there is a need to justify the validity of this argument. That is, to show that innateness in emotional movement exists and is definable.

Studies on emotional facial expression have found clear evidence of innateness across cultures and countries. However early work on body movement did not find these similarities and this caused a conflict. The subject caused great debate and argument within the behavioural sciences. The problem is that it is very hard to separate the expressive movements from the non-expressive. It is now accepted that the non-expressive movements are learned whereas there is an innate basis in the expressive movements. It is necessary to examine what is meant by the terms non-expressive and expressive movement in order to distinguish between the two.

For conversation the non-expressive movements can be categorised into three types [42]. These are speech dependent movements, expressive gestures, and speech regulators.

The speech dependent movements are further subcategorised into kinesic markers, kinesic stress and junctures, and kinesic demonstrators by Birdwhistell [42]. Kinesic markers are used to back up language structure such as verbs and nouns. Pointing out of the object of discussion is a common example. Kinesic stress and junctures are used to emphasise punctuation or to stress particular words. Kinesic demonstrators are used to illustrate an action or description.

Expressive gestures are a large class of body movements, which are expressive motions that are culturally specific, hence not included in expressive movements which are innate. These can be supportive of verbal communication but can also replace words with an independent meaning. Common examples are hand gestures or greetings. These sorts of gestures may be used to convey a specific emotion but they are not innate or universal.

Speech regulators are used to regulate and control conversational flow. These can be used by both the speaker, to check that the listener is understanding and following what he is saying, and also by the listener to respond that they follow or do not understand. The actual movement can be through subtle head motion, postural shifts or eye contact.

Innate expressive movements are the most important class, though the most difficult to recognise and distinguish. Several studies had shown innateness existed but claimed it did not represent specific emotions, but a rather a more general emotional state. However further studies have found cross cultural models for specific emotions [42, 44]. The problem lies again in the difficulty of separating what is innate from learned gestures.

The expressive movements can be best described in terms of three classifiers. Interpersonal attraction, relative status and level of emotional arousal. There are other factors but these three are most commonly used in studies.

Interpersonal attraction describes the attraction connection between the person expressing the emotion and the emotional stimulus, be it a person or experience. It describes a general positive or negative relationship between the two. If you like someone for example, then the relationship is closer, more direct and positive. If you dislike someone then you will avoid contact and make yourself inaccessible to them, you would react negatively. Here there can be sexual differences in the way barriers are used and the way the feeling is put across, especially in a male-female interaction.

Relative status is similar to interpersonal attraction but concerns the difference in status between the person and the emotional stimulus or experience. There are differences in the way people act according to their status over or under another person. If you are of a higher status then your actions can be more confident, however if you feel threatened then your own status can be affected. Dominance and control are at one end of the scale with submission and dependency at the other.

Level of emotional arousal is representative of the intensity or strength of the experience. The level of arousal can affect how a person may in turn be affected by a specific emotion. There are differences between feeling happy-contented and happy-ecstatic.

3.4.3 Other Emotional Design Considerations

There is evidence to suggest that emotions are felt in different parts of the body. This fits with the combination theory of emotional arousal, because the physical autonomic response occurs in various areas of the body. A good example of this is feeling tension in the stomach. This presents important design issues for an animation system. When body movements are described they are often classified by grouping areas of the figure, it makes sense to provide control over the figure for the animator in the same way.

3.5 Perception

Issues of perception and cognition can be important in the design of an animation system, more so in one which is based on emotion. There needs to be awareness of complications which can arise depending on the final application. It is important to understand how people see things and how they draw conclusions from what they observe. This covers areas from controlling the eye of the viewer to cross culture and cross gender differences.

It can be useful to look at exactly how people see movement and what can be done to control where the viewer looks. This is important for expressing the message that you want to send with a animation. If you want a figure to give off the feeling of happiness then it must give the message with all of the figure. It has been discussed previously that emotions are felt in different parts of the body. What is important is that conflicting messages should not be given from different parts of the body. The arm cannot express happiness if the stance is sad. If conflicting messages are given then the effect will not be natural and the viewer may become distracted.

When discussing innateness in the previous section cultural differences were discussed. This is important in how people see things, and the messages they get from them. A gesture from one culture may mean something completely different to someone of a different culture. There are also differences in expression and interpretation between children and adults, and men and women which need to be addressed. Children will express themselves differently to adults and women may express themselves differently to men. To express sadness a child may scream and cry, an older child might try to suppress the tears but they would express themselves in a different way. Even at this level I have made a lot of generalisations. People are different and character cannot be pre-built into the animation system, it must be definable to allow for the diversity in personality.

The basis of an emotional animation system must be flexible to cope with these issues. Representation of emotional expression can be kept to an innate universal level. The character and personality of the figure should be definable and adjustable by the user.

Chapter 4 The Design Structure of DEGAS

4.1 Tools Used

This chapter details specific design topics of the Dynamic Emotional Gesture Animation System, DEGAS. It provides information on the tools and hardware used to build the system. It also details design solutions to the figure and model structure, the emotional model used, and the overall user structure for the system. It gives a basis of the system as a background before moving onto the main chapters on the posturing and animation implementation.

4.1.1 Hardware

DEGAS has been designed on a Silicon Graphics Iris Indigo workstation, fitted with an Elan 4000 graphics card. It is recommended that this is a minimum specification for comfortable use. This provides the graphical power needed to make the use of the system easy, and more importantly, real-time. One of the major goals of the system was to enable the user to preview and adjust animation as it is produced. This requires the dedicated 3D hardware provided by this standard of workstation to maintain reasonable detail and fluidity in the models and animation.

4.1.2 Programming Language

The DEGAS system is written using the C++ programming language. This approach has several advantages. It enables the easy use of graphical toolkits and user interface tools. It also provides the possibility of porting to other computer systems. The core algorithms and programming can easily be transferred to another computer platform, only the graphical interface and 3D graphics would need adaptation dependent on the target platform.

4.1.3 Open Inventor

The graphics in DEGAS are handled using Open Inventor, an object-oriented 3D graphics toolkit [52]. It is produced by Silicon Graphics specifically for easy to use three dimensional interactive graphics. The emphasis is on ease of development, while providing a wide range of effects and most importantly the speed needed for interactive graphics. Open Inventor is based on the more general Open GL graphics standard also by Silicon Graphics. The differences between Open Inventor and Open GL are largely to do with control the programmer has over the graphics. Open Inventor aids the programmer by providing a 3D database and built-in event model for user interaction. So, with Open Inventor, the toolkit handles a large part of the display and viewing of the 3D graphics. The simplest program can place a cube in space and initiate a viewer to look at that cube. Open Inventor can then handle all other aspects including lighting, rotation and manipulation of the cube. If required various degrees of the control can be accessed by the programmer. What this means in practical terms is that development time of the 3D graphical display is reduced and more time can be spent on the underlying algorithms and control.

The Inventor toolkit consists of four tools for the programmer to use:

- A 3D scene database which contains the building blocks to create a hierarchical 3D scene, such as shapes, transformations and grouping nodes.
- A set of node kits for creating pre-built groupings of Inventor nodes.
- A set of manipulators which provide an interface between the user and the 3D scene.
- A component iibrary for Xt which provides simple viewing and rendering techniques.

The main advantage of Open Inventor for DEGAS is the hierarchical structure of the 3D scene database. The models are built up in a tree structure with various types of nodes linked together. These nodes can represent a variety of objects, for example properties, transformations, and shapes such as cubes, cylinders or spheres. A simple example of this sort of structure is shown in figure 4.1. The tree structure begins with a group root node which all scene graphs must contain. This has three children, transform A, shape A and a separator. The separator is a node used to group together other nodes and enable the hierarchical structure of the graph. This also has three children, a property node which can contain colour and surface information, transform B and shape B. When a scene graph is evaluated certain nodes, such as transforms, affect others in the graph. In this example transform B acts on shape B. These nodes act only on the nodes to the right-hand side and only on the same level or lower. That is, the effects propagate down the tree but not up, this is an important property of the separators. So in this case shape B is subject to the transform B, the property node and transform A. Shape A is subject only to transform A. The advantage of this structure when animating an articulated figure is that rotations at joints automatically propagate down the model to affect further joints and nodes. So for example a change in rotation at a shoulder joint will rotate the entire arm, providing the structure of the nodes is correctly ordered. The effects on shape B are calculated from right to left, so transform B is applied before transform A. These points are important in the design of articulated models and are discussed in further detail in the Section 4.2, Figure Design and Structure.

Open Inventor also provides a variety of techniques for gaining and manipulating information about the current state of a model. There are methods for finding the bounding box of a shape and the co-ordinate position and orientation of that bounding box. There are also techniques for constructing the transformation matrix for any shape in the scene graph, and also the corresponding inverse transformation matrix. A transformation matrix can also be broken down into its constituent rotations and translations. These techniques are very useful when using inverse kinematics to position the figure, and also when evaluating collision detection.

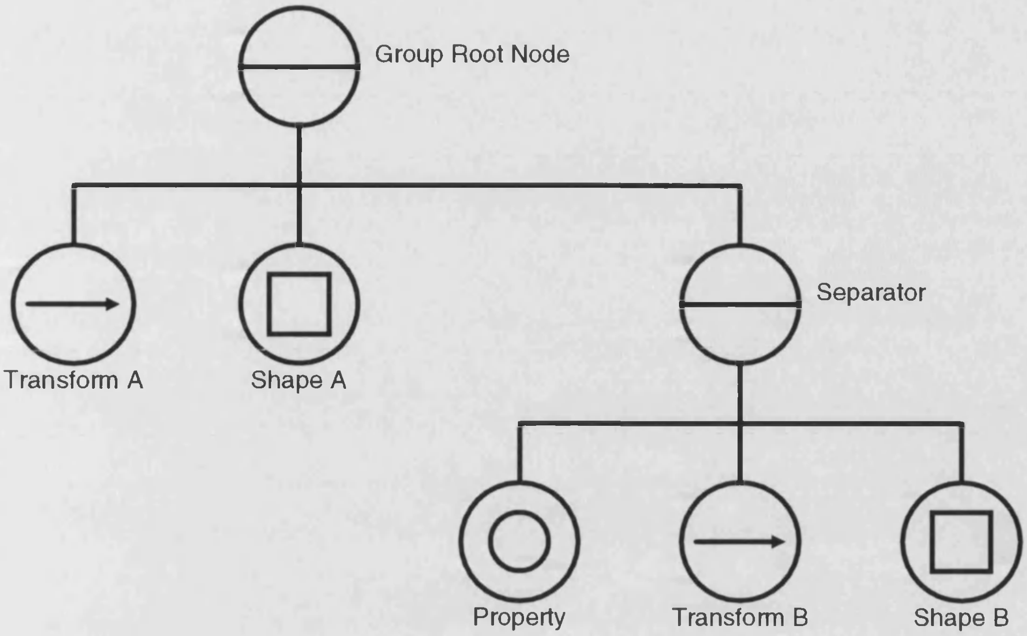


Figure 4.1 Example Open Inventor Scene Graph

Further to the development advantages of Open Inventor there are also portability benefits. Although Open Inventor is developed by Silicon Graphics its use is not restricted to Silicon Graphics machines. Open Inventor is available for a variety of systems including Silicon Graphics, Sun workstations and Windows NT. This enables a system developed using Open Inventor to be ported with only the window system specifics needing to be adapted.

The 3D standard for the World Wide Web the Virtual Reality Modelling Language, VRML, is also closely related to Open Inventor. VRML took much of its basis from Open Inventor and integration of models and animation would require little extra work. This provides the possibility to present animation on web sites in user controlled 3D. Rather than being restricted to a set viewpoint for a finished animation the user would be able to interact with, and move within the scene.

4.1.4 X Windows and Motif

Silicon Graphics machines use the X Window System and UNIX for user interface and operating system. X Windows was originally developed by MIT's Project Athena and Digital Equipment Corporation with input from various other companies. Version 11, commonly referred to as X11, is now in its second release and development is handled by the X Consortium. The X Window System has been developed to be used on multiple systems and make development of cross-platform applications easier [53, 54].

For ease of development within X Windows DEGAS uses Motif. This is a toolkit for X Windows which provides the functionality for interface widgets such as windows, buttons, menus and sliders. It is based on the Xt Intrinsics which provide easy access to the lower levels of the X Window system. The relationships of X Windows, Xt and Motif in relation to hardware and operating system is shown in figure 4.2. Motif gives DEGAS a uniform, clean and familiar look as it is widely used for other products on X Window systems.

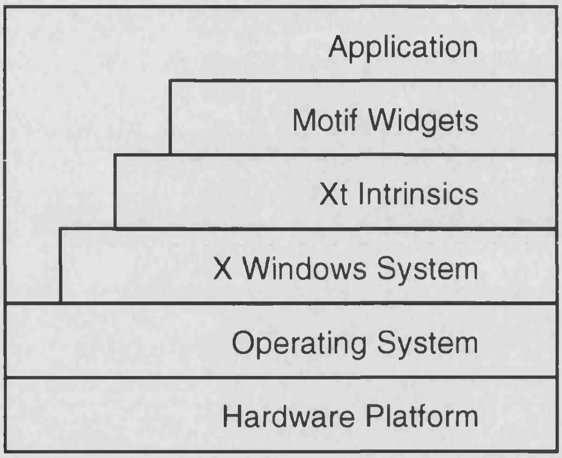


Figure 4.2 X Windows and Motif Relationship

Open Inventor also has extensive support for the use of Xt components and Motif. When using Open Inventor the program control is via a main loop which reacts to events, called SoEvents, using event handlers. The events can be anything from keyboard presses to mouse movement within a viewing window. When using X Windows there is a similar main loop which again handles events, called X Events. When Open Inventor is used with X Windows the main loop is controlled by Inventor which provides event translation from Xt events, see figure 4.3. This means that X Events can interact with Inventor objects and the scene database. In this way buttons and sliders provided by Motif can be used to manipulate the Open Inventor scene database.

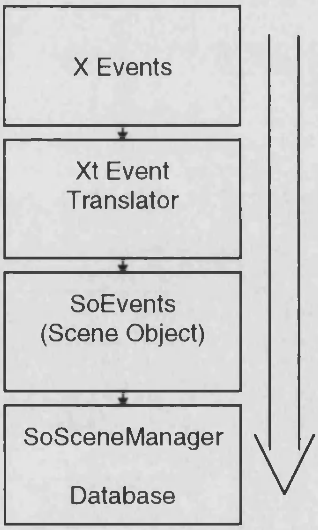


Figure 4.3 Event Processing in Inventor with X

The user interaction with the main program occurs by specifying callback functions and associating these functions with events. For example a slider which controls the joint angle would have a callback function associated with the movement of the slider. So each time the slider is moved by the user the main loop of the program is interrupted by the callback function. Once the callback function has executed control is returned to the main loop. Callback functions and their use in DEGAS are discussed further in the Implementation chapters.

4.2 Figure Design and Structure

This section details the design of models to be used with DEGAS. The model appearance has been kept simple for several reasons. By providing a simple but recognisable form, the animator can concentrate on the motion and control of the figure. The important aspects of proportion and structure can still be maintained. Using a simpler figure also helps in the development of DEGAS. Use of more complex figure models has been left as a possible further development.

4.2.1 Figure Structure

The basic figure structure for a human model is rooted at the base of the spine. This is shown in figure 4.5. From this root a hierarchical structure based on joint connections and groupings describes the construction of the body. In this way operations such as translations and rotations affecting one object will affect all objects below it in the tree. Thus all transformations applied to the left lower arm will also apply to the left wrist and left hand.

In order to keep the program real-time it has been necessary to build the figure from the basic shapes of spheres, cylinders and boxes. Spheres are located at all joints to make the figure appearance smooth and connected. The limbs and back are constructed from cylinders. The back is also connected to boxes which make up the bulk of the torso. Hands and feet are also simply made from boxes. The head is made up of a large sphere with smaller spheres for the nose and eyes to give the head direction. See figure 4.4.

The root of the figure could be located at a different point in the figure structure. For instance if a figure is walking the actual root switches between the left and right ankles. This involves restructuring of the model and associated joint rotations. The advantages are that this can help eliminate the effect know as 'moon-walking' where, when walking, the steps do not match the forward movement of the figure. However the restructuring can be computationally expensive, and it is advantageous to look at other solutions to the problem. These are discussed later in the Animation Implementation section. DEGAS does not however assume the figure to be structured in this way and models may be used that have the root in at a different point. The models used in examples all have the root at the base of the spine, simply because this point is the most versatile.

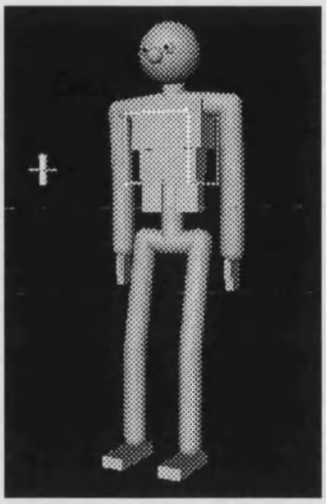


Figure 4.4 Human Figure Model

The figure is based on the model used by Badler [6] and is designed with 24 joints, see figure 4.6. There are several simplifications made to reduce the number from that of a real human. The back and neck are reduced to six joints. This gives a good range of movement for expression while keeping it manageable for the program and the user. The shoulders are reduced to three joints, one at the spine, one mid-shoulder and one at the top of the arm. The hands and feet are simple blocks because the complexities of these areas are such that further study would be needed for more intricate implementation.

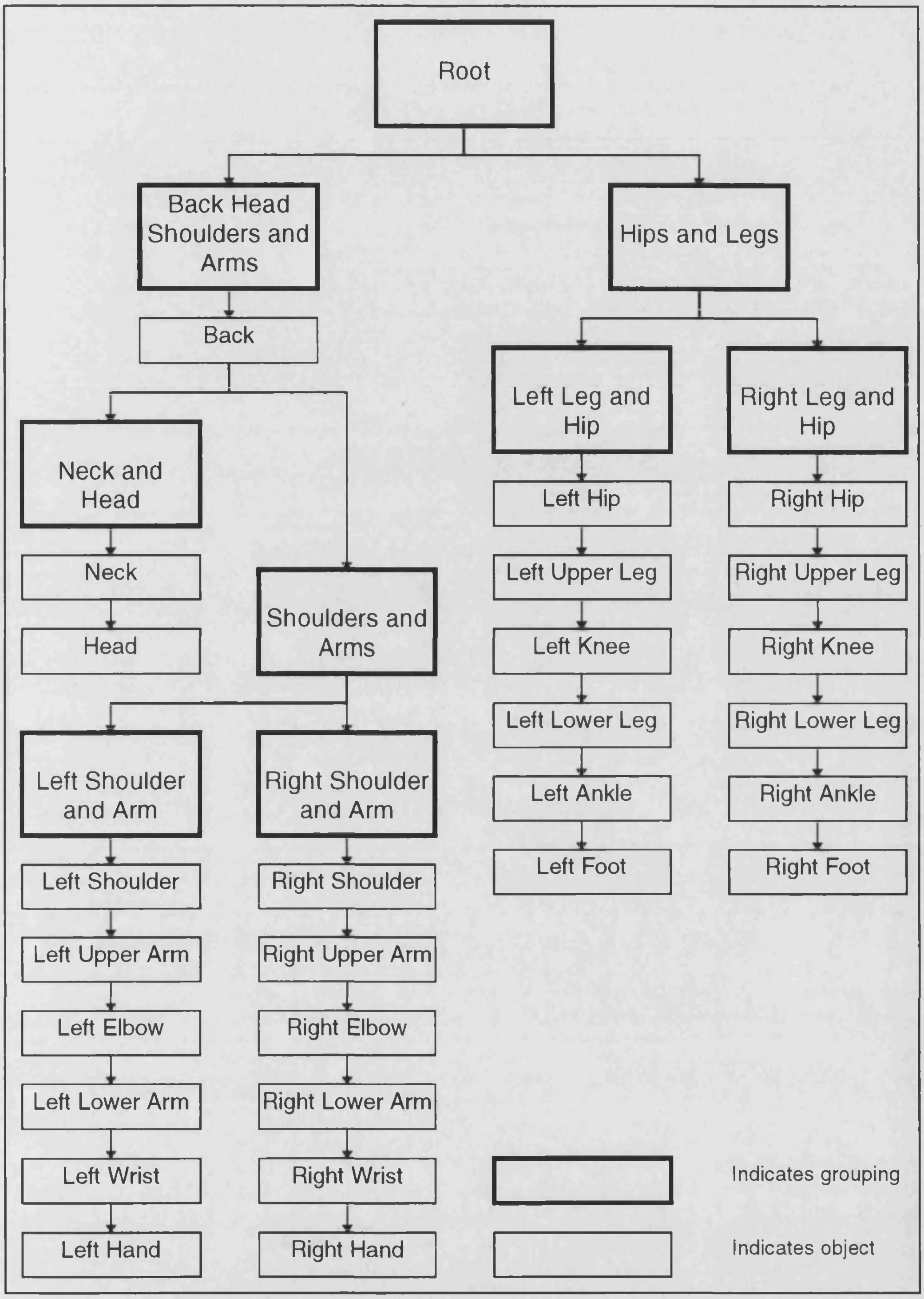


Figure 4.5 Structure of figure with base of hip as root

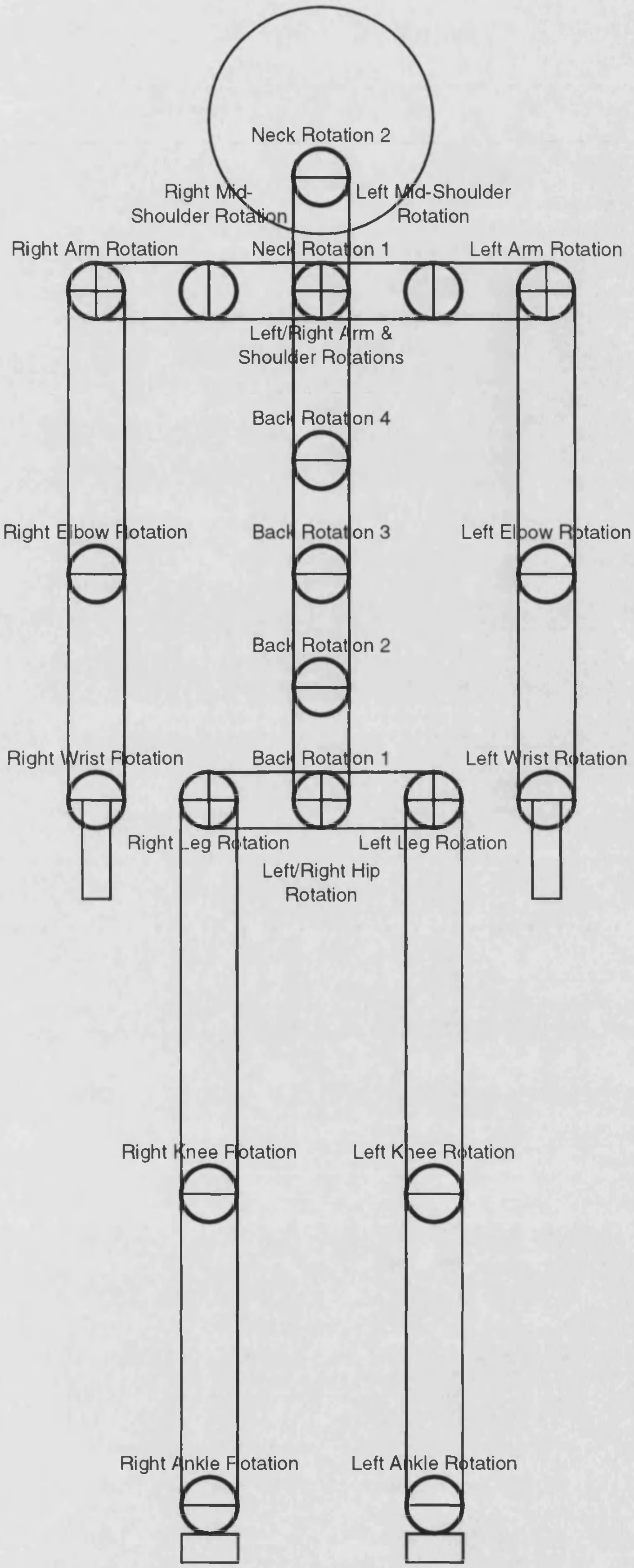


Figure 4.6 Figure Joint Construction

4.2.2 Joint Structure

The rotation at a joint can be constructed in two ways. The rotation can be expressed in quaternion or Euler angle form. A quaternion consists of an axis and a rotation about that axis. The Euler form is described in terms of rotations about each of the primary axes, X, Y and Z, and the order to apply the rotations.

With quaternions the expression of the rotation is simpler to represent but in some ways more difficult to work with. The way joints are constructed in the human figure and in the Badler model make using the Euler form more appropriate. Joints in the human figure are often restricted in how they may be moved. For example the knee joint has only one degree of freedom under normal circumstances. For more complex joints where there are more degrees of freedom they are connected. This means that a movement in one degree of freedom may affect the movement in the other. This lends itself to the Euler angle form of joint composition, where the order of application of the joint rotations in the primary axes has a controlling effect.

The Euler implementation is constructed from up to three rotations. For each joint there may be a flexion, pivot and twisting rotation, each about a primary axis [36]. Flexion is the main rotation associated with a joint and is made about the flexing axis. Pivot rotation is about the pivotal axis and this rotates the flexing axis. Twisting rotation is made about an axis aligned with the direction of the joint, for example in the back the twisting axis runs along the spine. As is the case with Euler angles the order in which the rotations are applied is of great importance. Here, where applicable, the twisting rotation is applied first, followed by the flexion and then pivoting. Table 4.1 details the joints in the figure and the corresponding rotations, flexion, pivot and twisting applied at that joint.

The models used in DEGAS have two sets of the appropriate flexion, pivot and twisting rotations. One set is used and adjusted by DEGAS, the other set is the basic set of joint rotations which define the standard posture of the model. In the construction of a figure to be used in DEGAS the standard posture rotations can become quite complex, it is best if these are kept separate from the rotation which the user will manipulate. This method makes manipulating and resetting the figure much easier. More information on the Inventor file structure and model construction used by DEGAS can be found in Appendix B.

No.	Joint	Rotations Applied
1,2,3	Back Rotation 1	PFT
4,5,6	Back Rotation 2	PFT
7,8,9	Back Rotation 3	PFT
10,11,12	Back Rotation 4	PFT
13,14,15	Neck Rotation 1	PFT
16,17,18	Neck Rotation 2	PFT
19,20	Left Arm and Shoulder Rotation	PF
21,22	Left Mid Shoulder Rotation	PF
23,24,25	Left Arm Rotation	PFT
26,27	Left Elbow Rotation	FT
28,29	Left Wrist Rotation	PF
30,31	Right Arm and Shoulder Rotation	PF
32,33	Right Mid Shoulder Rotation	PF
34,35,36	Right Arm Rotation	PFT
37,38	Right Elbow Rotation	FT
39,40	Right Wrist Rotation	PF
41	Left Hip Rotation	F
42,43,44	Left Leg Rotation	PFT
45	Left Knee Rotation	F
46,47	Left Ankle Rotation	FT
48	Right Hip Rotation	F
49,50,51	Right Leg Rotation	PFT
52	Right Knee Rotation	F
53,54	Right Ankle Rotation	FT

Table 4.1 Flexion, Pivot and Twisting details for figure joints

4.2.3 Underlying Figure Structure

Aside from the basic information of joints and angles it is also useful to have information on other joint related values. This is held in an underlying figure structure. Information is stored concerning joint names, constraint values and linkages between joint rotations.

The joint names are useful for grouping joints together. Inventor provides the functionality to name rotations in the data file. These names can then be used to search for and gain information on joints in the Inventor scene graph. The same methods can also be used to change values of joints and other properties in the scene graph. Constraint values contain the physical limits of a particular joint. They can be specific to individual models and also updated by the user or the program as needed. Linkage information is important information on how connected joints are related. This is not simply how the joints are connected to each other but information about how exceeding constraint limits can be handled. These concepts are explained further in the Implementation chapters.

The underlying information structure is intended to be a resource to help with internal manipulation of the figure. It allows for greater control and more realistic adjustment of the models. The content of the structure is powerful way to expand the system and it is intended to be extended with further development.

4.3 Emotional Model Used

The emotional model used by DEGAS is based on the Plutchik emotion wheel. This defines eight basic emotions, Joy, Sadness, Acceptance, Disgust, Fear, Anger, Surprise and Anticipation.

An important consideration in the choice of this model is that it is defined in emotional pairs. This provides a balance for the model and also helps with the distinction of what the emotions actually mean. The emotional model has to be clear and understandable to the user. With the English language there can be grey areas in interpretation of what the actual words mean. When presented with pairs the distinction can be made more clearly, lessening any confusion.

The complex emotions can be made from blends of the basic ones. In Plutchik's emotion wheel there are restrictions on what it is sensible to blend. Secondary emotions are defined around the outside of the wheel, and blending of opposites is not part of the model. In DEGAS there are no restrictions on the blending of emotions. The basic eight are presented as a palette from which the animator can mix as they wish. This gives the animator more control over the end results and also allows for the possibility of emotion masking. Emotion masking is the process of trying to hiding a feeling from others by acting differently. For example a man may be sad but try to hide it by acting happily. To actually achieve a complete mask is very difficult, there will be signs that others can recognise if they look for them. Emotion masking is not inherently built into DEGAS, however taking the free blending approach allows the exploration of masking in testing, and possible further development.

The emotional state of the figure is defined by eight values, one for each basic emotion. These values are restricted to the range zero to one in increments of 0.01. It is intended that a value of 0.75 or greater for an individual basic emotion or a blend of several basic emotions is considered an intense emotion. There are no restrictions to what can be blended or to what degree. These decisions are left to the animator and what is trying to be achieved. The details of the emotional model in use are discussed in greater detail in the Posturing and Animation Implementation chapters.

4.4 Structure of the System

4.4.1 Basis of DEGAS

This section is an overview of how DEGAS operates and how a user can produce an animation using the system. It gives a grounding in the basic design concepts and structure of the animation system before the main chapters on the implementation of DEGAS. The use of DEGAS can be divided into two connected components, the posturing system and the animation system. DEGAS is a key frame animation system, hence the animator first sets up a sequence of postures, the key frames. Then the animator will use the computer to calculate the in-betweens which connect the key frames to produce the animation. This follows the traditional animation process where the lead animator would set out the key frames. They would then pass these on, with instructions about timing, to other animators to do the in-betweens. The key ideas and concepts are presented over the next two sections, these are then explained in greater detail in the Implementation chapters.

4.4.2 Posturing

The animation process begins by loading an Inventor model and a related DEGAS information file. The Inventor model file is a text file in the standard Inventor format, and must conform to the DEGAS specifications. This requires that certain named rotations and objects be defined in the file. The DEGAS information file contains information about how the model should interact with DEGAS. The information in this text file must conform to DEGAS specifications detailed in Appendix A. The DEGAS file is an integral part the animation system, it provides the means for user definition of model interaction. Some of its features are explained briefly in this section and but its use is explained in greater detail in the Implementation chapters. The model and DEGAS files can be specified on the command line when running the program. If just the model file name is given then the associated DEGAS file, if available, will also be loaded. Once DEGAS is running different model and DEGAS files may be loaded, either together or separately.

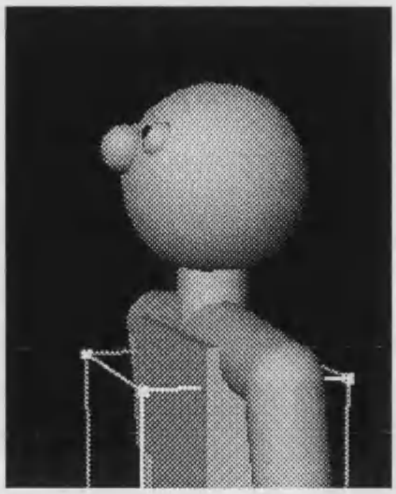
DEGAS presents the user with a control panel with buttons which access the various features of the system and a number of views of the model to be animated. The number of views can be specified on the command line and can take the values one, two or four. If one or two views are used then the user is presented with a standard view or views. In these the view point can be fully manipulated by the user, so the model or animation can be viewed from any angle. If four views are selected then the user is presented with a view from the front of the model, a side view, a top down view and a standard view.

The main posturing process is the setting of two or three postures through which to animate. If two postures are set then the animation is simply from the first to the second. If three postures are set then the animation will be from the first to the third, through the second. The second option using three postures allows a greater range of movements to be defined, and also helps create smoother transitions between connected movements. The problems this addresses are explained further in the Animation section.

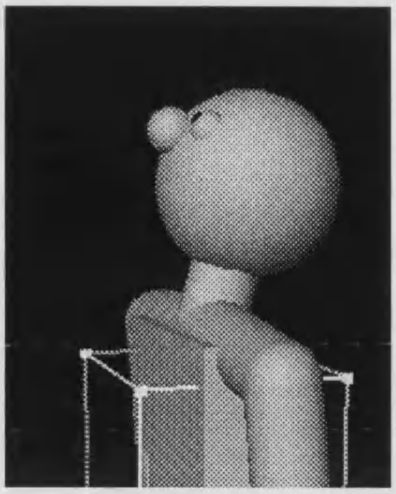
The figure control for the setting of postures has three layers. A base layer is for low level control, the other two layers are high level controls. The base layer defines explicit control over joint angles. This provides the animator with total control over the posturing. The second layer contains a set of functions which can control groups of joints in the figure. The functions are taken from a list of posturing elements considered important to expression and body language [45]. These functions are restricted to particular areas of the figure, for example the function raise leg can only effect leg and hip joints. The third and final layer contains a set of global functions which can affect the entire figure. These include functions such as stance control and user defined global controls. The interaction of each layer with the model is defined and controlled by the DEGAS information file.

The user also has control over the emotional state of the figure. This is represented by a set of eight sliders, each representing one of the eight basic emotions in the emotional model used by DEGAS. The most important aspect of the posturing system is that the interpretation of the high level control functions, the second and third layers, depends on the emotional state of the figure. If the user changes the emotional state then the posture will change accordingly. This emotional interaction with the functions is based on theories of innate body language and emotional expression [46, 47]. As there are limitations to the current theories in this area the interaction can be controlled, to a certain extent, through the DEGAS information file. The emotional state is particular to a specific posture, thus the two or three postures for the animation need not have the same emotional state.

There exists a system for defining and managing constraints and limits. The constraints on the movement of the model are defined in the DEGAS file and these can also be adjusted within DEGAS itself. If, when adjusting the figure using low level controls, a limit is reached then the figure will not be adjusted further. However if the figure is being adjusted using high level controls then there exists the option to try and accomplish the movement by passing back the action to a connected joint. For example if when raising the head using the top neck joint of the figure the limit is reached, then the motion could be passed lower neck joint. This can be seen in figure 4.7. Picture (i) shows the limit of the top neck joint. Further application of movement in this area results in the situation shown in picture (ii), with the extra movement applied to the lower neck joint.



Picture (i)



Picture (ii)

Figure 4.7 The Passing Back of Movement

This control system was developed to suit the application's goals and requirements. The high level posturing controls provide the animator with the tools to set a basic posture and then use the low level controls fine to tune it. The emotional interaction helps define the basic posture taking into account the emotional state of the figure. Through the use of the DEGAS file the interaction can be tuned to specific models giving each a character of its own.

Throughout the posturing process when a value is adjusted the effects are immediately applied to the figure. This real-time interaction is very important in allowing the animator to see what effect the adjustment is having. If a slider is moved then the figure is adjusted accordingly as the slider is moving, not only once the new slider position is set.

Access to the posture control functions is provided in several ways. From the main control panel window there is a button labelled Movement. This brings up a further window with options to bring up controls for specific areas of the body, the Global controls, the Neck and Back, the Arms and Shoulders, the Legs and Hips and the Head. Through these options the animator can access high and low level functions sorted by body area, so if they are working on a particular part of the posture then all available controls are easily accessible. On the main viewing window there is a menu bar which gives quicker access to particular high level functions. This helps if the animator knows what function they want to use and wants quicker access to it. Finally the animator can click on the figure itself in the main viewing window. Depending on what part of the body the click, an option box or low level control box will appear. Again this is for ease of use.

The animator has the option of saving or loading the posture. When a posture is saved the format contains values of the high and low level functions, not the specific joint values. This is so the animator can use the same posture for different models or characters. The use of the DEGAS information file ensures that the posture file is interpreted in a reasonable manner. When an animator has finished editing a posture, then it is set as one to be used in the animation process. Once the animator has set the two or three postures they wish to use then they are ready to move onto the set-up of the animation process.

4.4.3 Animation

The actual animation process is concerned with the set-up and manipulation of control splines. These are calculated according to the emotional state of the figure and other constraining factors. They can be fully manipulated for fine tuning by the animator within the limits of their definition.

The splines are joined Bezier curves, chosen for ease of use and adaptability. They are represented on a graph with time on the x-axis and position on the y-axis, see figure 4.8 for an example. The position is in terms of initial posture to final posture. The splines are initially set based on the joint they will be applied to and the dynamic emotional state. The emotional state of the model is dynamic as the emotional states of the postures being animated between may be different. The constructed splines are stored in a spline collection of up to fifty separate splines. Each joint rotation and variable, such as translation, has a reference associated with it to one of the splines in this database. The references are also alterable according to the needs of the animator. In this way the animator may define a control spline and associate it with several joint rotations.

When the splines have been set the animation can be viewed in real-time. Again this helps the animator see results immediately and make adjustments as necessary. Certain timing functions are available to help keep the animation smooth and realistic. These involve keeping the feet touching the floor and automatic translation adjustment for walking movements. Once the animator is happy with the animation they can spool the resulting values to a file for later replay. For a longer animation the animator can join several short sequences together, or alternatively create a longer sequence from within DEGAS.

Throughout the system the goals of user definition and control are maintained. The animator has the ability to adjust and adapt all aspects of the animation process. A key aspect to this goal is the production of real-time results as adjustments are made.

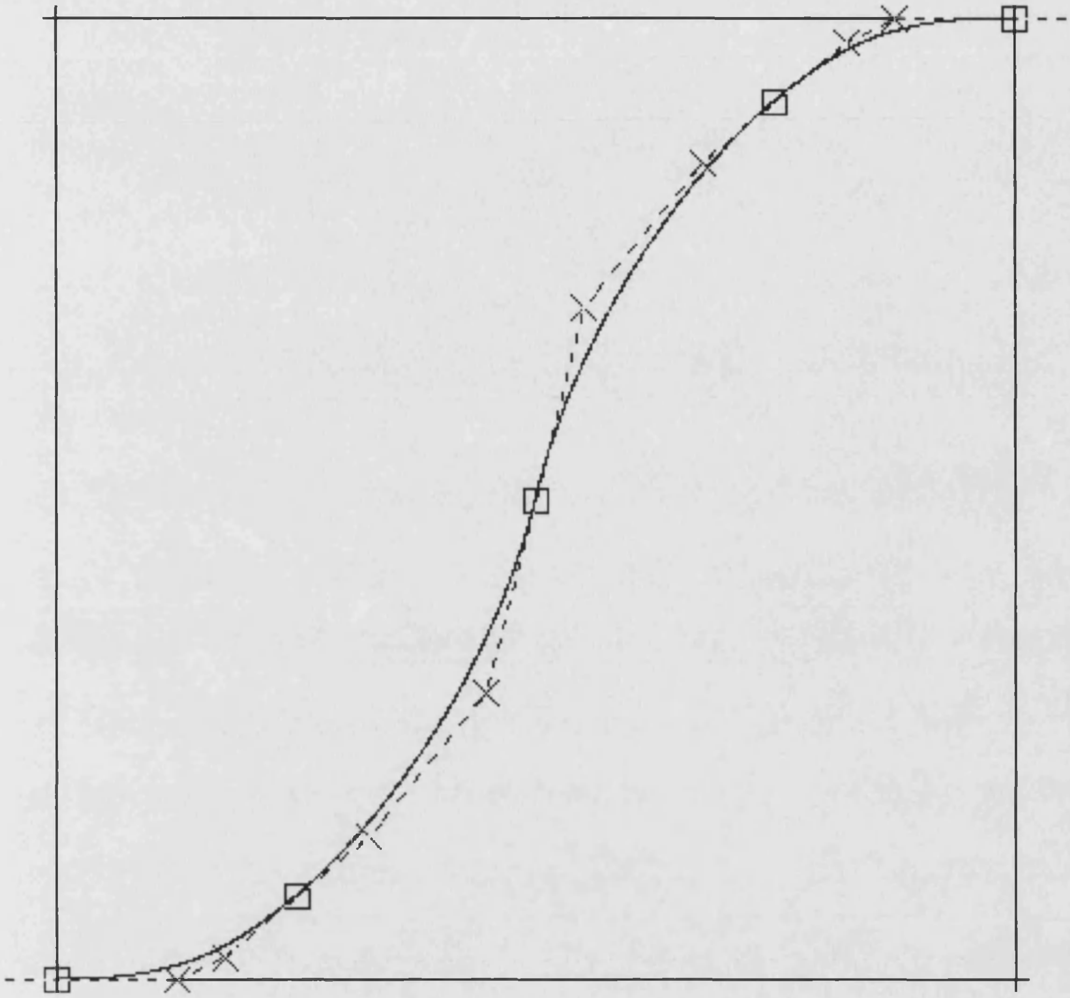


Figure 4.8 Bezier Curve Used for Animation.

Chapter 5 Posturing Implementation

5.1 Introduction

The implementation of DEGAS can be separated into two connected components, the posturing system and the animation system. This section details the design and execution issues relating to the posturing system.

For an animation to be produced in DEGAS the key-frames must first be set using the posturing system. The animator has a choice of setting two or three postures. If two postures are used then the animation will be a motion from the first posture to the second. If three postures are used then the animation will be from the first posture to the third, going through the second. The mechanics of the transition between postures is dealt with in the Animation Implementation section.

The setting of a posture has particular requirements in a system such as DEGAS. The basis of DEGAS is the emotional interaction throughout the animation process. When it comes to animating emotions, there are extra considerations to be taken into account. In emotional animation there is a greater emphasis on the key frames, as how a figure is positioned at the key points will determine the overall feel of a movement. The postures have to reflect the emotion being conveyed. It is important therefore that the controls presented to the user operate on the emotions, not just on the posture. For this a structure is required that integrates emotion with the posturing system in a simple and intuitive way. Where finer posture control is needed, the animator should still be able to make detailed adjustments. For these reasons the posturing system in DEGAS has been designed to allow the animator to set a basic posture with high level control functions, and then to fine tune the posture created with low level controls. The emotional interaction occurs in the use of the high level control functions. These control functions act on groups of joints in the figure to produce a general movement such as the lowering of the back. The emotional state of the model determines how the values of these functions should be interpreted. Thus the emotional values are integrated into the process of setting up the posture of the model.

The use of traditional animation techniques in the posturing process is examined with respect to DEGAS. This details how the techniques can be utilised within DEGAS and how they can be used to help in the emotional process. Exaggeration and secondary action can be used to great effect when trying to express a particular emotion. Other artistic elements such as composition and colour can also be used to enhance the emotional effect. These techniques are important even if they are not to be used. If their effects are not understood then the incorrect message may be given.

5.2 Levels of Posture Control

The approach used for the body posturing in DEGAS is a three-layered structure. At the base level there is control over the joint rotations explicitly. This gives total control over the positioning of the model but it is difficult and cumbersome to use. There are then two layers above this which are general body controls that can affect more than one joint. The majority of the high level functions are in the second layer, which gives control over specific areas of the body. The remaining high level functions are global controls, such as general stance adjustment, where control is over the whole of the body. These form the third layer. All the high level functions are tailored to emotional posturing and animation. As a basis for the functions I have used a list of body movements and positions that are important to body language [45]. The list was extensive, so for DEGAS I have tried to concentrate on elements particular to emotional body language. These elements are also restricted by what is possible in the animation system. Certain movements and static posturing components, such as finger movement, are not possible as DEGAS does not support complex hand animation. The list also detailed movement and static posture components separately. For DEGAS these have been combined into one list of posturing set-up control functions. This is because the key-frames in the posturing system represent a snapshot of an animation. So posture and movement elements need to be treated as one.

Name	Joints / Sub-Groups
Global Group	Back Group, Head Group, Shoulder Group, Arm Group, Hip Group, Leg Group, Global Translation, Global Rotation
Back Group	Back Rotations
Head Group	Neck Rotations
Shoulder Group	Left and Right Shoulder Rotations
Arm Group	Left Arm Group, Right Arm Group
Left Arm Group	Left Arm Rotations
Right Arm Group	Right Arm Rotations
Hip Group	Left and Right Hip Rotations
Leg Group	Left Leg Group, Right Leg Group
Left Leg Group	Left Leg Rotations
Right Leg Group	Right Leg Rotations

Table 5.1 Joint Rotation Groups

The figure is divided into localised area groups, where sets of joints are logically linked together. Further to this, groups themselves are joined together to form larger groups, with all joints and motion controls eventually being part of the global group, see Table 5.1. In this way posturing functions can be restricted to specific areas, which helps with function interaction and definition. Table 5.2 details which joints previously described in Table 4.1 and Figure 4.6 in the Figure Design and Structure section belong in which rotation group.

Rotation Group	**Joints**
Back Rotations	Back Rotations 1-4
Neck Rotations	Neck Rotations 1-2
Left and Right Shoulder Rotations	Left Arm and Shoulder Rotation Left Mid Shoulder Rotation Right Arm and Shoulder Rotation Right Mid Shoulder Rotation
Left Arm Rotations	Left Arm Rotation Left Elbow Rotation Left Wrist Rotation
Right Arm Rotations	Right Arm Rotation Right Elbow Rotation Right Wrist Rotation
Left and Right Hip Rotations	Left Hip Rotation Right Hip Rotation
Left Leg Rotations	Left Leg Rotation Left Knee Rotation Left Ankle Rotation
Right Leg Rotations	Right Leg Rotation Right Knee Rotation Right Ankle Rotation

Table 5.2 Rotation Groups

5.2.1 The Joint Low Level Controls

Basic low level control is provided for the animator to fine tune each joint rotation. For all joints, excluding the back and neck joints, there are controls to explicitly adjust the pivot, flexion and twisting angles where applicable, see figure 5.1. For convenience these controls are limited to the values in the range -1.00 to +1.00 in steps of 0.01. These values do not correspond directly to the joint angle however as they are then weighted by values given in the DEGAS information file. This weighting is important in giving better control to the animator and also overcoming design issues relating to the construction of the models to be animated.

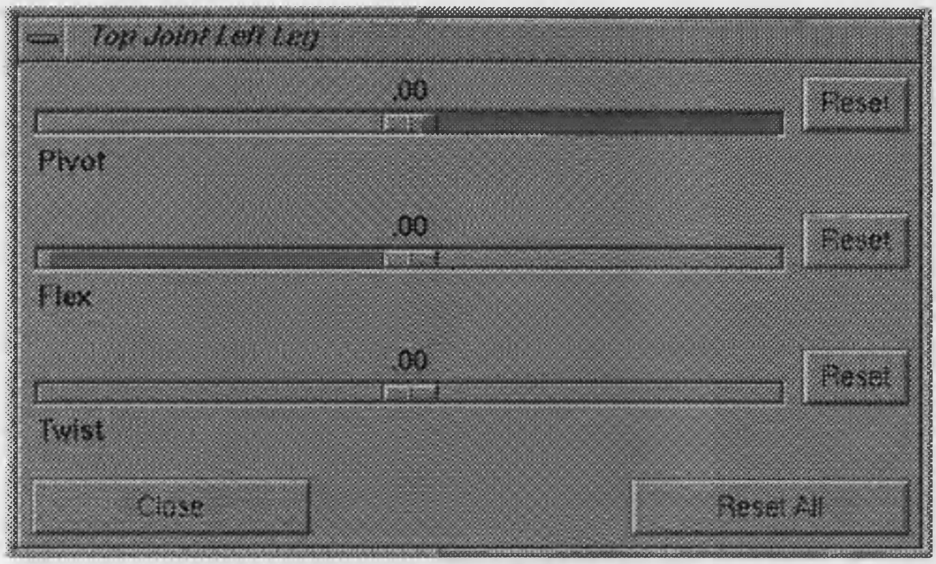


Figure 5.1 A Sample Low Level Control Panel for the Left Leg Rotation

By allowing a weighting to the value set in the posturing system the animator has more control on the effects of their adjustments. If the joint angle has very little movement within its constraints then the animator can specify a weight of less than one. This will mean that the animator will have more precise control where they need it most. A weight of 0.5 would mean that an adjustment of 0.1 translates to a change in the joint angle of 0.05. If a joint angle has a larger range of movement then the weighting can be made greater than one to allow this control.

Low level controls are useful to fine tune high level control function effect, and as such can be defined in a way suitable for the animator. For example, if the models high level control functions are suitably comprehensive for what the animator is trying to achieve then the low level controls can be made more precise. As the high level functions can be used to posture the figure close to the desired position then the low level controls do not need to be so general. The weighting for some joints can thus be reduced to 0.25 or less to allow actual steps in joint angles to be 0.025 or lower.

When a connected figure is constructed, because of the Inventor processes involved, some joint angles may not act in the way you would expect. The orientation of joint angles can be twisted such that a positive rotation on the left knee may be it the opposite direction to a positive rotation on the right knee. The problem can be illustrated by looking at the hip and leg section of a model, see figure 5.2. The diagram at the top shows simplified legs in the splits position before being rotated into their natural state. The arrows are positioned on the knee joints and show the direction of the positive axis about which the knee rotates. The diagram at the bottom shows the same legs now in their more natural state. The axes at the knee joints are now pointing in opposite directions. This means a positive rotation at the left knee joint would be in the opposite direction to that of the right knee joint.

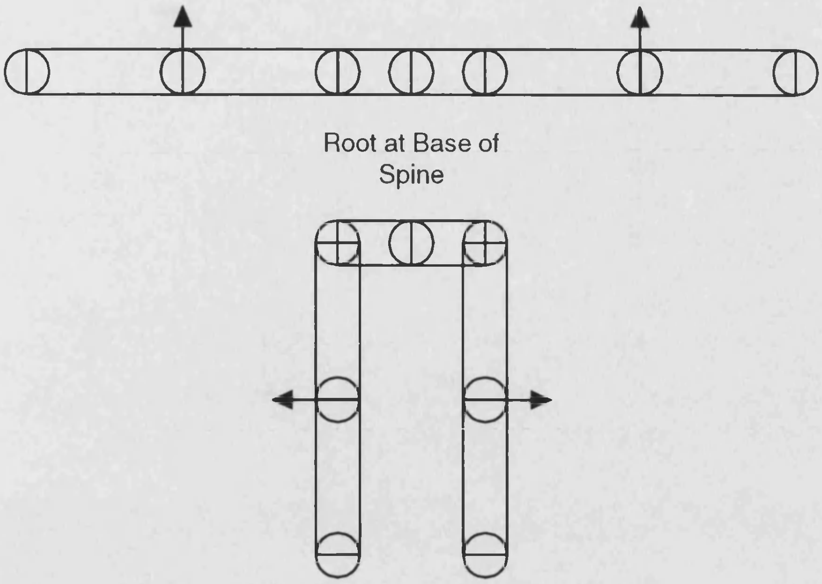


Figure 5.2 Hip and Leg Section of the Model

There are several ways to solve this problem. An adjustment in the structuring of the model would work, but can get unnecessarily messy. A simple change to make the weighting on one joint negative will also rectify the problem, and this is how DEGAS treats the problem. This method also opens up possibilities for the animator to tailor the rotations of the models to suit their requirement. It gives the animator limited control over model construction and manipulation, which is not usually possible. It is also very useful when using a non-human model in the system. For example the knee joint on a duck will bend in the opposite direction to that of a human. In this case it makes sense to have the positive rotation at this joint the opposite to that of human models. This is achievable using the weights defined in the DEGAS information file.

The back and neck joints are treated as a special case as the movement of these joints is often linked. The back and neck in general move as one connected component and the low level structure designed for adjustment reflects this. The pivoting, twisting and flexion angles for all back and neck joints are controlled by three values which are then multiplied by weights for the individual joints. The basic structure is shown in figure 5.3. There are three such structures used, representing pivoting, flexion and twisting of the back.

Figure 5.4 shows the control panel relating to this structure as it is presented to the animator. From here the user can adjust and compare the weights relating to the back and neck joints. There is no restriction placed on the animator in what values they assign the set of weights. In this way some interesting effects can be achieved by mixing positive and negative weights.

```
Back_Pivot_Structure {
        BPValue;           //   Back Pivoting Value
        BR1Pweight;        //   Back Rotation 1 Pivot Weight
        BR2Pweight;        //   Back Rotation 2 Pivot Weight
        BR3Pweight;        //   Back Rotation 3 Pivot Weight
        BR4Pweight;        //   Back Rotation 4 Pivot Weight
        NR1Pweight         //   Neck Rotation 1 Weight
        NR2Pweight         //   Neck Rotation 2 Weight
        }
```

Figure 5.3 Back Rotation Structure

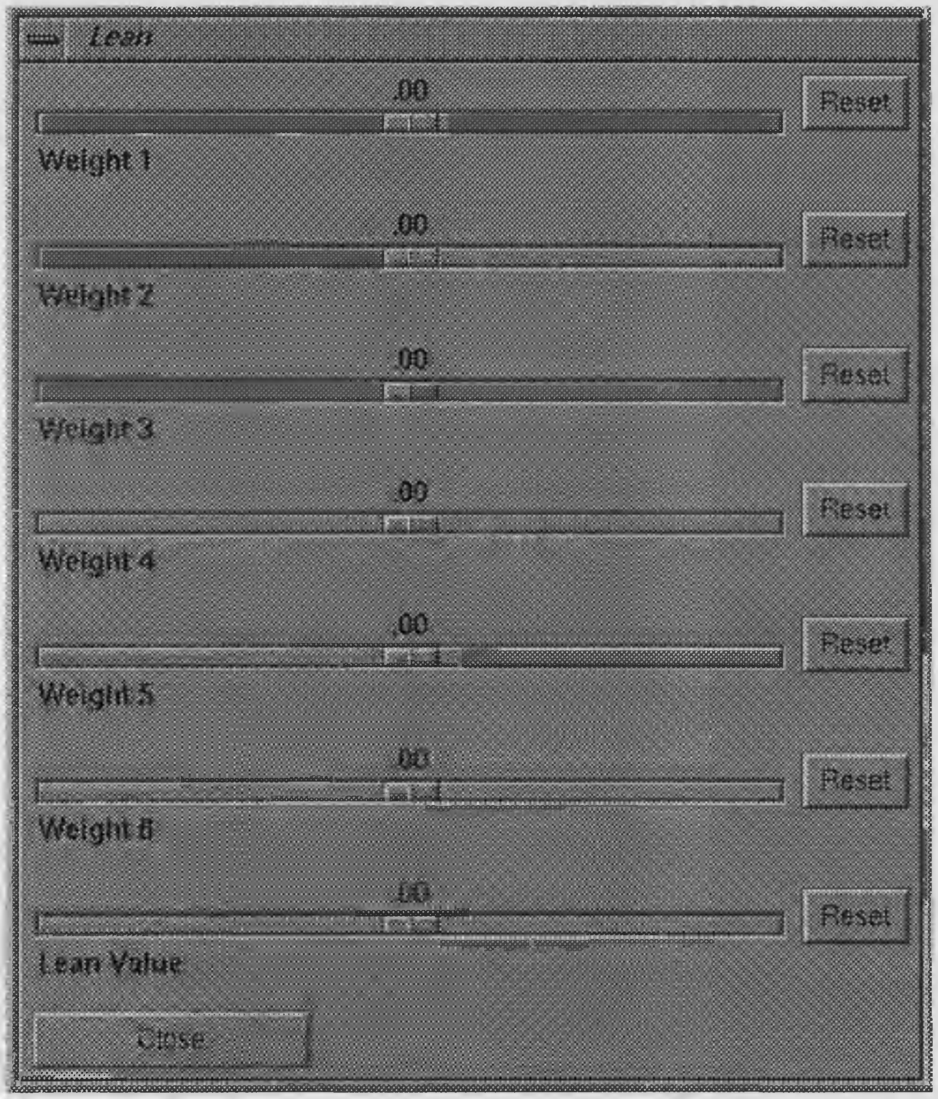


Figure 5.4 Low Level Back Control Panel

With this representation there is little resulting restriction on actual back control, but the ease of use is greatly increased. The relationship between the joints is clearer and easier to see, so the animator is able to relate individual back joints to other connected joints in a simple and intuitive way.

5.2.2 Global Translation and Rotation Controls

Manual adjustments of the global translation and rotation of the figure are low level controls, however because of their nature the method of adjustment is different to that of the joint angles. Rather than providing sliders to adjust these values an Inventor Transform Box Dragger is used. This is displayed as a cube made up of lines in the viewing window, see the first picture in figure 5.5.

The box is positioned on the torso of the model being postured. It is adjustable by using the picking mode of the viewing window, which is entered by clicking on the pointer icon at the top left hand of the viewing area. The Transform Box Dragger contains several methods of adjustment dependent on where the animator presses the left mouse button. Translation is adjusted by selecting one of the faces of the cube. When the left mouse button is depressed a cross with arrows will appear to indicate the direction of adjustment. This can be seen in the second picture in figure 5.5. With the mouse button still held down the animator may move the mouse up and down or left and right to adjust the translation of the figure in the appropriate directions. The rotation adjustment is done by selecting one of the edges of the Transform Box Dragger, as in the third picture in figure 5.5. Here once the edge is selected, with the left mouse button still depressed, left and right, or up and down, movement of the mouse will rotate the figure in the appropriate manner.

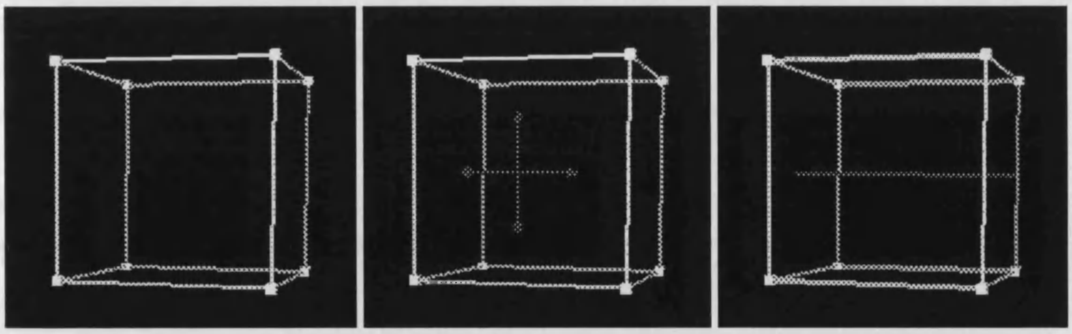


Figure 5.5 Transform Box Dragger Examples

The interaction between the transform box and the translation and rotation nodes of the figure is done in a similar way to the slider interaction with the posturing values. The Transform Box Dragger has a series of callback functions attached to it, which are called when adjustment occurs. These callbacks adjust the translation and rotation nodes in the model and also the posture values.

There also exists some automatic adjustment of the translation of the figure, to control positioning of the feet relative to the ground. This is discussed later in the High Level Control Definition Chapter. This method is not strictly high level, in the sense that there is no user control over the interaction and there is no emotional input. However, the method is more complex that the standard low level control and can affect the translation of the figure in more than one direction.

5.2.3 The High Level Control Functions

Table 5.3 gives the list of high level functions listed by region, name and groups affected. The list is by no means definitive and the system is designed to allow further expansion of the functions and changes to how they are implemented. Some functions have yet to be implemented.

The Global region, which represents the third layer, contains seven high level control functions. The first two control the general stance of the figure, whether it is open or closed and whether it is forwards or backwards. The general stance of a person can be very important in bodily communication and expression. It can give clues to the general mood of the person and their attitude towards others they are interacting with. Finally there are four user functions, which are definable in the DEGAS information file. They are intended to provide the animator with the ability to program commonly used posturing controls into a model. This can help save time and provide the model with a distinct character.

The Back and Head region contains six high level control functions. Lower and Raise Back control functions are used to control the trunk of the figure. The two function are distinct in that one does not cancel the other. This is because the way a model raises its back may not be the opposite of the way it lowers it. The Lower and Raise Head control functions work in a similar way. The Look At and Turn Towards (WB) control functions are directed functions. As well as specifying a value or values for the function the animator also specifies a direction to which the control function applies.

The Arms and Shoulder region contains six high level control functions. Shrug and Negative Shrug are control functions which simulate the raising and lowering of shoulders. These can also be adapted to affect the arms, bringing them up to enhance the movement. Join Arms describes the movement of bringing the arms together. There are three Point At control functions representing the left arm, right arm and both arms. These functions are directed and therefore need the animator to specify an area which is the focus of the motion.

Region	Control Function	Affects
Global	Stance Open/Close	Global Group
	Stance Forward/Back	Global Group
	User Defined (1-4)	Global Group
Back and Head	Lower Back	Back Group, Head Group
	Raise Back	Back Group, Head Group
	Lower Head	Head Group
	Raise Head	Head Group
	Look At	Head Group
	Turn Toward (WB)	Back Group, Head Group, Shoulder Group
Arms and Shoulders	Shrug	Shoulder Group, Arm Group
	Negative Shrug	Shoulder Group, Arm Group
	Join Arms	Arm Group, Shoulder Group
	Point At (BA)	Arm Group, Shoulder Group, Back Group
	Point At (LA)	Left Arm Group, Shoulder Group, Back Group
	Point At (RA)	Right Arm Group, Shoulder Group, Back Group
Legs and Hips	Join Legs	Leg Group, Hip Group
	Lean (Legs)	Leg Group, Back Group
	Raise Leg (LL)	Left Leg Group, Hip Group
	Raise Leg (RL)	Right Leg Group, Hip Group
	Leg Point	Leg Group, Hip Group
Hands	Hand to Head	Arm Group
	Hand to Neck	Arm Group
	Hand to Face	Arm Group
	Position Hand	Arm Group
Feet	Raise Foot (LF)	Left Leg Group
	Raise Foot (RF)	Right Leg Group
	Tip Toes	Leg Group

(WB) = Whole Body (BA) = Both Arms (LA) = Left Arm (RA) = Right Arm

(LL) = Left Leg (RL) = Right Leg (LF) = Left Foot (RF) = Right Root

Table 5.3 High Level Functions

The Leg and Hip region contains six high level control functions. The Join Legs and Legs Apart functions can be used to control the distance between the legs of the figure. This has a similar effect to the opening and closing of the stance but is more localised. The distance moved is intended to be subtle though the resulting effect can be great. The Lean Legs control function is strictly not just related to the legs and hips as it can also affect the back. It is also similar in effect to the Stance Forward control, though the intention is that Lean Legs should be based around the leg area. As the figure is rooted at the hips adjustment of Lean Legs may also affect the global translation and rotation. This is handled automatically by DEGAS and control over the effect is not required by the animator. The Raise Leg functions are self explanatory in that they are simply there to raise the legs in an easy and flexible manner. The final control function in this region is Leg Point. This is not simply as it sounds, the 'pointing out' of something using the leg, it is a subtle but important movement. The orientation of the leg in relation to other people during a conversation or interaction is important in giving information about emotion and feeling towards them. For example it can be used subconsciously as an indication of interest or dislike.

The Hands region contains four high level control functions. Hand to Head, Hand to Neck and Hand to Face are similar goal directed posturing controls. The positioning of the hands gives important information about the emotion of a person. They are often used to protect or hide feelings, though the action of hiding can give away the information it is meant to be hiding. Position Hand is another goal directed posturing control. It is intended to give the animator quick and easy general positioning, which can then be fine tuned. These functions are not implemented in DEGAS, they are listed as a plausible future extension. Some of the actions can still be achieved by using the point at control functions.

The Feet region contains three high level control functions. The Raise Foot (L/R) functions are simple controls to manage foot movement separately from the more general leg movements. Tip Toes is another simple control which may be tailored to suit the movement onto the toes in a variety of situations, such as standing or sitting. This function can also adjust the global translation of the figure to maintain the position of the model relative to the floor.

5.3 Emotion / Control Function Interaction

The most important aspect of the high level control functions is how the values are translated into posturing on the model. In addition to the normal constraints of limits, and what the function is trying to achieve, there must also be a dependency on the emotion. This is the essence of the DEGAS posturing system. The interpretation of the high level control functions is based on the emotional state of the figure. In this way a posture set by high level functions may look completely different if you change the emotional state, as the interpretation is altered. Even so, because of the nature of the high level control functions certain essential criteria, such as specific posturing, can still be maintained.

Figure 5.6 shows how the posturing process is structured in the creation of a specific static posture. The process of interpretation, which constructs how the figure is postured, depends on four factors, the emotional state, the constraint values, the high level control functions and the low level values. The emotional state is static as it applies to the single posture. The constraint values are also static and are linked to the emotional state. The base constraint values are determined by the DEGAS information file associated with the model. They may be adjusted by the animator from within DEGAS using the constraint panel.

However the emotional state of the figure can adapt these values to reflect physical changes brought about by a high emotional state.

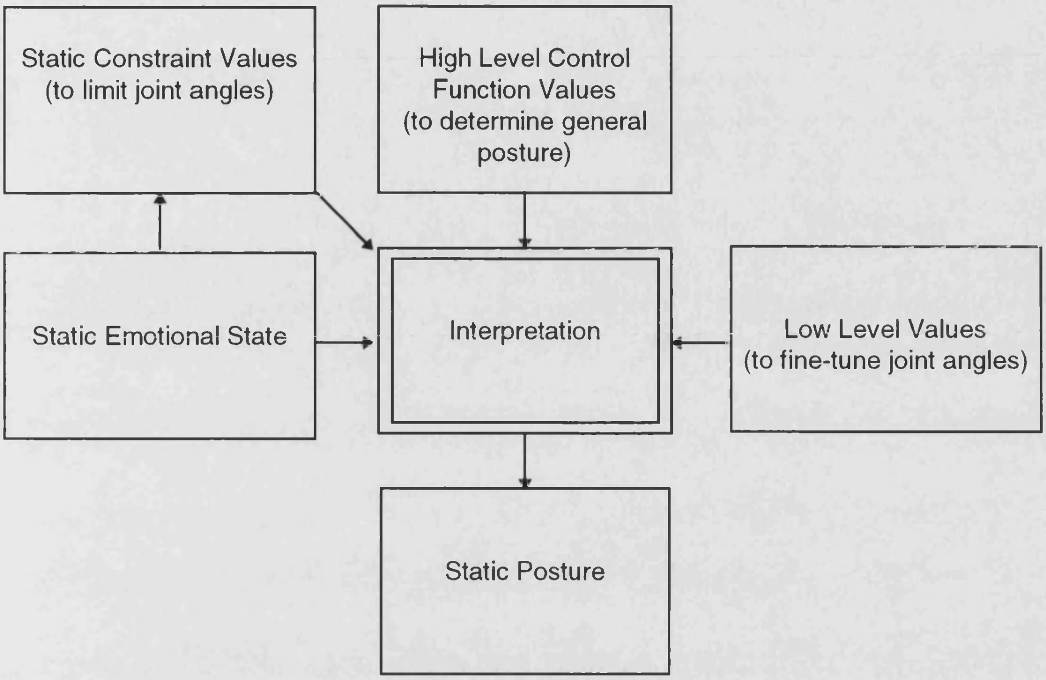


Figure 5.6 Posturing Process

The specific values of joint angles are defined by the equations in figure 5.7. The joint angle value is the sum of all high level function contributions affecting it plus the low level fine tune contribution. This value is also subject to the defined constraints. The individual high level function contribution depends greatly on what the function is trying to achieve. For simpler control functions, such as raise leg, the relationship between the emotional state and the function value is linear. For other functions, such as turn toward, the relationship is more complex.

$$\theta_i = \eta_i + \sum_j \lambda_{ij}$$

$\theta_i =$ Rotation value of joint angle i

$\eta_i =$ Low level contribution for joint i

$\lambda_{ij} =$ High level contribution of function j for joint i

$$\lambda_{ij} = f(v_j, E)$$

$f =$ Function which defines interpretation of v_j

$v_j =$ Values of high level function j

$E =$ Emotional state

Figure 5.7 Posturing Equations

How the emotion / joint interaction operates is determined by looking at the basics of human body language and trying to separate the innate emotion factors. The idea is to determine general posture elements rather than specific emotional gestures. Gestures are often open to interpretation through situation and cultural differences so they are avoided in the system. Factors are defined in a non-rigid way so as to allow for adaptation and difference of interpretation. The areas of science which DEGAS deals with in these areas are often open to discussion and development. DEGAS is designed to adapt in these areas because of these reasons. The animator has limited control over the emotional factors through the DEGAS information file.

The emotional factors are translated into parameterised posturing modifications. This is to enable mixing of the emotional factors in the same way as the base emotions themselves are mixable in the emotional state. In this way the emotional interpretation for a complex emotion, one which is made up from two or more base emotions, may be calculated.

5.3.1 Control Adjustment Pipeline

When a control slider is adjusted, whether low or high level control, the posture update process is activated. This pipeline process is shown in figure 5.8. It starts with the user input, usually the adjustment of a control slider. The sliders have a series of ordered callback functions connected to movement or change in the slider value. The slider itself is not inherently connected to the posture structure values, this connection is the second section of the pipeline process. The first callback function attached to the slider adjusts the posture structure values of the posture being edited. The third section of the process is the update of the figure joint values. The number and type of callback functions called at this stage depends on the control being adjusted. There are separate update functions for the various areas in the body. These functions will re-interpret the high and low level controls in this area, taking into account the adjustments made and evaluating conflictions. Once the interpretation is complete the updated output of the process is displayed on the screen.

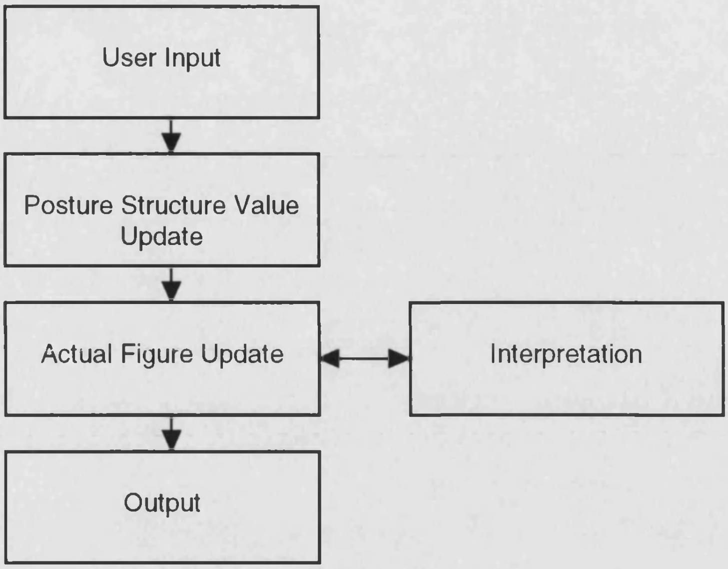


Figure 5.8 Posture Update Pipeline

5.3.2 The Emotions and the Posturing System

In order to understand the connection between the posturing system and the basis of emotional interaction it is necessary to look at the emotions in terms of posturing effect. Each emotion from the emotional model used in DEGAS is examined in terms of its contribution to posturing elements. It is significant to note at this stage that some emotions have greater effect on certain areas of the body, and little effect on others. This reflects the common descriptions people will give of emotions being felt in a particular part of their body [44].

In order to define a basis for these interactions great care has been taken to research body language and emotional expression. Converting these stated descriptions to visual effects is not a simple or straight forward task. Much of the research in this area is imprecise and contains grey areas. DEGAS takes the information as a basis of ideas for the interaction in the posturing system. It then allows adaptation and refinement by the animator as fits their requirements within the constraints of the system and what the action is trying to achieve.

As the emotional interaction in the posturing system is based solely on the high level control functions, much of the discussion will be in relation to those already implemented in DEGAS. Though, as DEGAS is designed to be expanded, the discussion will be general enough to apply to future posturing elements.

Before looking at the individual emotions used in the model by DEGAS it is important to understand how DEGAS defines the emotions represented in the emotional model. These emotions are not taken solely at dictionary definition. The common use and implications of the words are important, as this is what an animator using the system will be used to. It is necessary to remember that words such as "anger" and “anticipation”, can mean many things to different people. DEGAS has addressed this problem by looking for core definitions which should be understandable and acceptable to most people. In addition to giving the basic emotions a core definition, each is also examined in a more of general sense. This is done by describing the base emotions in basic terms without referring to other emotions. It is useful to look at whether an emotion is positive or negative as these attributes can help understanding of what the emotions represent. It can also help determine the general bodily effect of directed emotions in particular. That is feelings which have a source or direction, for example a feeling of Acceptance towards a particular direction can result in general posturing elements, such as stance, being pointed in this direction.

5.3.2.1 Positive and Negative

The general terms of positive and negative are useful in describing the basic emotions and their broad behaviour. It is also useful in defining the emotions in relation to each other and defining guidelines with respect to mixing of emotions.

Positivity is associated mostly with the emotions Joy and Acceptance, though other positive complex emotions can be achieved through mixing. The effect of positive emotions is that of lifting and forwardness. The mild effects can cause the raising of the head and back. Then, as the emotion becomes greater, the stance can become more open and forward [44, 45, 48]. Increased forward lean is often associated with positive movement, or more subtly a reduction in backward lean can have the same effect. Directed control functions can become more enthusiastic reflecting interest and recognition.

Negativity is associated more with the basic emotions of Sadness, Disgust and Fear. The posturing effect is roughly opposite to that of positivity. Instead of movement toward and outward, the effect is away from and more usually inward [44, 45, 48]. The head and back movement is down and away, curling inward. The stance is moved away and becomes closed. More subtle effects are similar to those of positivity, a reduction in positive elements can have an significant effect. A slight movement back or reduction in forward movement is apparent in directed posturing methods.

It is worth noting that, although advice about the mixing of emotions is given, there is no restriction placed on the animator. It is left to the user to decide whether a given combination is sensible in a given situation for a character. The general advice is that positive emotions, basic or complex, work best when mixed with other positive or neutral emotions. Similarly negative emotions work best when mixed with other negative or neutral emotions. However if a mixture works well and produces the required results then the use is perfectly acceptable.

5.3.2.2 Joy

Joy or Happiness is a very positive feeling [48]. It is often associated with other feelings such as excitement or contentment, to give more specific information about the feeling. There can be many causes of Joyfulness, which produces a large range of feelings which are often simply described as being happy. The emotional model used by DEGAS is specifically designed to allow complexities in emotion through the mixing of basic emotions, thus a large range of Joyful emotions can be achieved. Other basic emotions which can be mixed to good effect with Joy are Anticipation, Surprise and Acceptance.

When looking at posturing elements associated with Joy the common theme is that of positivity. Joy is a positive feeling and the adjustment to the posturing should reflect this. The stance becomes more open and toward directed components. The head and back are raised in the general motion of the posture upwards. Directed high level control functions are more certain. General posturing elements will become exaggerated as the emotional value increases.

5.3.2.3 Sadness

The basic emotion paired with Joy is Sadness, which is a largely negative feeling. It is similar in many ways in terms of definition to Joy. Sadness covers a large range of feelings due again to the large number of causes. These can be represented by mixing this basic emotion with others in various amounts to produce the desired effect. Sadness mixed with anticipation can result in what might be called dread. Other basic emotions which can be mixed to good effect with Sadness are Disgust, Fear and Anger.

In terms of posturing Sadness has the reverse effect of Joy. Associated with sadness is a reduction in muscle tone [48], which can cause a number of alterations to the posture. The general movement is downwards, lowering of back, neck and shoulders. Directed movements are less enthusiastic and lower they might be under normal conditions. The stance becomes closed, and movement is away or inwards, towards the body. Negativity is apparent in all posturing methods.

5.3.2.4 Anticipation

Anticipation, or expectancy is a neutral emotion. It is the feeling of knowing what is about to happen or expecting something. It depends on the overall represented emotions as to whether this is a positive or negative feeling. If Anticipation is mixed with Joy then it becomes positive, if it is mixed with Sadness then it becomes negative. Other basic emotions which can be mixed to good effect with Anticipation are Acceptance, Fear and Anger.

Movement and posturing associated with Anticipation is in readiness for what is expected. Slight contraction of the stance can have a subtle but significant effect on the feeling expressed. Movement is generally inward towards the main body, arms move in, legs become bent as the figure crouches. Muscle tone is increased as tension is increased in anticipation [48]. Directed control functions are adjusted slightly away from the goals to re-enforce the stance adjustment.

5.3.2.5 Surprise

Surprise is paired with Anticipation and is similar in use in many respects, it is basically the opposite feeling. It is the feeling of shock or in a more mild respect, being taken aback. Again the overall feeling is dependent on other basic emotions, a person can be surprised by good things and bad. If this basic emotion is mixed with Fear, then the result would be a negative feeling. If it were mixed with Joy then the result would be a positive feeling. Other basic emotions which can be mixed with Surprise to good effect are Disgust and Anger.

Posturing when Surprised is dependent on the other emotions applied. There is a definite loss of muscle tone [48], which causes movement to be exaggerated and extreme. The direction of movement is indicated by the values of the other basic emotions. A joyful surprise would be open, where as a fearful surprise would cause contraction for protection. The stance movement is backward away from the source of surprise, this can be re-enforced greatly by movement of the limbs and exaggerated head motion.

5.3.2.6 Acceptance

Acceptance is a positive feeling of approval or assent. It is not a common word used by people to describe their feelings, but it can be very useful when mixed with other basic emotions. For example Joy and Acceptance can be used to represent the complex emotion of love. Acceptance can also be mixed to good effect with Anticipation, and to a lesser more subtle extent with Sadness, Disgust and Anger.

The positivity of Acceptance is overriding in terms of its posturing effects. Stance adjustment is forward and open, to reflect the positive relationship between the figure and the viewer or direction of interaction. Leaning and turning toward, through the back and legs, is exaggerated and enhanced. The use of leg pointing is more directed to show interest. General posturing of the limbs is similarly more forward and toward the direction of interest and Acceptance.

5.3.2.7 Disgust

Disgust is the opposite of Acceptance and a negative feeling of disapproval or dissent. It is more commonly used by people to express how they are feeling and, as the opposite of Acceptance, this is useful to gain better understanding of the meaning and context of Acceptance. It can be mixed to good effect with Sadness and Surprise.

The posturing elements with Disgust are opposite to that of Acceptance. The stance becomes closed, but the movement away from the direction of interaction is more apparent.

Directed posturing methods are reduced and less pointed in their goal direction. The leaning and general posturing elements are directed away where possible. While limbs can move forward in general, the direction of the hand or foot is back and away.

5.3.2.8 Fear

Fear is largely a negative feeling, though the consequences of the emotion itself can be positive. This feeling of anxiety is usually directed, there is a definite source of the feeling, which is normally local. It can be mixed to great effect with other negative feelings or neutral feelings such as Surprise, to give the feeling of fright.

In terms of posturing the effects of Fear are largely in line with a negative reaction. The stance movement is away from the direction of interaction, the cause of fear. The stance can also close up greatly, with the hunching of the shoulders and back, and the bending of the knees. Protective measures, such as the raising of the arms are also directed inwards [48]. Directed posturing methods are moved away from their goals to re-enforce anxiety or apprehension. There is also a more general movement away from the source of the fear, backward movement of the limbs and turning away through the back are enhanced.

5.3.2.9 Anger

Though paired with Fear, Anger is not so obvious or well defined as other pairings. Anger is not necessarily a positive or negative feeling, this is largely dependent on the cause of the Anger and the effect of other basic emotions. Again it works best when mixed with other negative or neutral feelings.

The postural effects of Anger are largely caused by the increase in muscle tension [48]. The stance moves more toward the source of anger, and general posturing elements are reduced in line with the muscle tension.

5.4 Limits and Constraints

This section discussed the management of postural limits and constraints within DEGAS. It also discusses the resolution of conflicts which may occur when using high level control functions. There can exist situations where the criterion of one high level function contradicts that of another. To resolve this there is a hierarchical system which means some high level control functions take precedence over others.

5.4.1 Constraint Definition

Constraints which apply to the model being animated are contained in the associated DEGAS information file. They are measured in radians and they are modifiable from within DEGAS using the Constraint Adjustment Panel, see figure 5.9.

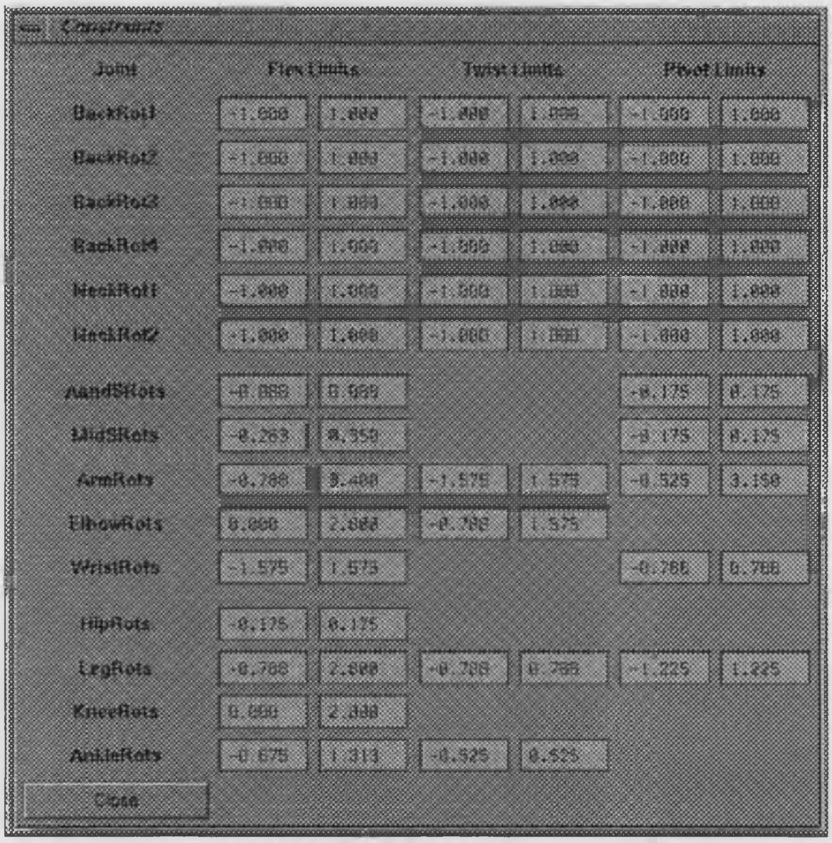


Figure 5.9 Constraint Adjustment Panel

The limit values used for the test model in DEGAS are those shown in the Constraint Adjustment Panel, figure 5.9. This data was obtained through measurement of the limits of a human volunteer. The values represent a usable data set for testing purposes and are not meant to be an accurate assessment of the average human capabilities.

When adjusting the posture using low level controls the constraints are absolute. That is, if the adjustment is greater than the limit then the movement is not possible. The animator must reassess their objective and adjust the posture or constraint values accordingly. When adjusting the posture using high level control functions, constraints are used in a more complex way. Depending on what the control function is trying to achieve, movement constrained at one joint may be transferred to another. This is done using the connections detailed in the underlying figure structure.

5.4.2 Automatic Constraint Adjustment Through Emotional Interaction

When a human is under extreme emotional conditions then the usual physical limits can change. The effects of high pressure and high emotion situations can result in adrenaline being released into the body, increasing the physical capabilities. Similarly a low emotional state, that of relaxation for example, can lower the physical limits which the subject would use to exert themselves. DEGAS aims to emulate this by using the emotional state values to alter the physical constraint values. The actual values contained in the constraint structure and displayed by the constraint panel are not changed, the change is internal. When an adjustment at a joint angle is made, it is checked against the constraints of that joint angle. The value it is checked against is a modified value based on the emotional state and the constraint structure information. Thus the constraint information adjustable by the animator, and displayed in the constraint panel, is not modified itself. Rather the modified value based on this information is used internally to keep it distinct from the user defined information.

To define the interaction between emotion and constraint values the definition of emotions and their expected results is necessary. For mixing purposes it is recommended that an individual emotional state value be no greater than 0.75 under normal circumstances. Greater values indicate a very high, extreme, emotional state. Though when considering the sum of mixed emotional state values a combined value of 1.0 or more can have less extreme effects. For example consider the emotional states shown in figure 5.10. The values given represent the emotional state variables Joy, Sadness, Anticipation, Surprise, Acceptance, Disgust, Fear and Anger respectively.

State A	(0.5, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0)
State B	(0.0, 0.8, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0)
State C	(0.5, 0.0, 0.0, 0.3, 0.3, 0.0, 0.0, 0.0)

Figure 5.10 Sample Emotional States

State A is representative of a Joyous emotion. The total of the emotional values is 0.5, and this is considered well within the boundaries of normal feeling. State B is representative of a Sad emotion. The total of the emotional values is 0.8. As this is a single emotional value this is considered an extreme emotion. State C represents the complex emotional combination of Joy, Surprise and Acceptance, what you would feel if you were surprised by something pleasant. Although the sum of the individual emotional state values is 1.1, it could produce acceptable results as none of the individual values are greater than 0.75. The actual effect of each of the individual emotional state values is difficult to determine. It is based on the definable emotional interaction, so could be different for different models. The grey areas associated with the psychological theory only serve to cloud the issues. DEGAS can only provide guidelines to the animator to what is acceptable to the system in terms of defining emotional states, and the resulting emotional interaction. Within these guidelines the results are expected to be reasonable.

This information suggests that some scaling is needed, to reflect complex emotions defined by multiple base emotions. Currently this assessment in DEGAS is based on the total of the squares of the values in the emotional state. This allows for the mixing of emotions and keeps the constraint adjustment in accordance with the criterion above. Going back to the examples in figure 5.10. For State A the sum of the squares is 0.25, for State B the sum of the squares is 0.64 and for State C the sum of the squares is 0.43. The threshold recommended for extreme values is a sum of the squares of approximately 0.5. This value is only an approximation of where extreme effects may be encountered, as the effects are dependent on the actual emotion, the emotional interaction and the high level control functions used.

Under normal use the adjustment is slight, a change of the order of +/- 5%, though when extreme emotional states are used then the adjustment can be as much as +/- 50%. The formula for calculating the constraint adjustment is given in figure 5.11. P represents the basic percentage for constraint adjustment, and e_1 ... e_8 are the individual emotional state values. If P is negative, when there is a low emotional state, this value is further modified by multiplying by 0.25. This is to represent the less drastic change in constraint adjustment when in a low emotional state.

$$P \qquad = ((e_1^2 + e_2^2 + \ldots + e_8^2) - 0.5) * 100$$

Figure 5.11 Constraint Adjustment Formula According to Emotional State

Taking the examples given in figure 5.10 once again. State A is a low emotional state, the initial calculation of P gives the result -25%. As this is negative it is further adjusted to give a final P value of 6.25%. State B is a high emotional state, the calculation of P gives a value of +14%. The initial P calculation for State C gives a value of -7%. As this is negative it is further modified to give a final P value of 1.75%.

5.4.3 Constraints and the Underlying Figure Structure

Beneath the surface structure of joint angle values there is a structure which holds important information on the connections and use of the joints in the model being animated. This information is model specific and can be defined by the animator using the DEGAS information file. The full uses and definitions of the DEGAS information file is detailed in section 5.5.

The format of the underlying structure is given in figure 5.12. The structure consists of three sub-structures, the Limits structure, the Connections structure and the Extra structure.

Limits Structure

```
typedef struct {
   float pivotLower;
   float pivotUpper;
   float flexLower;
   float flexUpper;
   float twistLower;
   float twistUpper;
} Limits;
```

Connections Structure

```
typedef struct {
   int jointAngle;
   int jointDir;
} Connections;
```

Connections connections[55];

Extra Structure

float extra[55];

Figure 5.12 Underlying figure structure

The Limits Structure contains the constraint values of a joint. It is assumed that the constraint data is symmetrical for simplicity. This means that there exists one set of constraints which applies to the left and right arms and shoulders, and similarly the left and right legs and hips. Thus for the 24 actual joints there are 15 limit structures, detailed in figure 5.13.

BackRot1	*BackRot2*	*BackRot3*	*BackRot4*
NeckRot1	*NeckRot2*		
AandSRot	*MidSRot*		
ArmRot	*ElbowRot*	*WristRot*	
HipRot			
LegRot	*KneeRot*	*AnkleRot*	

Figure 5.13 Limit Structures

The first group contains the six back and neck limit structures which each apply to individual joints. The second and third groups refer to the arm and shoulder joints and the leg and hip joints respectively. Here each structure corresponds to both the left and right joints. In each structure there are limits for the pivoting, flexion and twisting where applicable. These are defined as simple floating point numbers corresponding to the upper and lower limits of the joint angle.

The Connections Structure is made up from an array of simple structures containing two values, each part of the array representing a joint angle. The two values are a reference to the Extra structure, *jointAngle*, and a direction for the rotation to take place, *jointDir*. The values in the Extra structure are added to the low and high level contribution at a joint to give the joint value during the interpretation stage of posturing. The *jointDir* values indicate whether a rotation at the connected joint should be positive or negative, should the rotation at the initial joint be too high. If the value is one then the rotation is positive, if the value is zero the rotation should be negative. For example, consider a joint angle with a connection where the value of jointDir is zero. If the limit of the first joint angle is exceeded then the movement may be passed on to the connected joint angle. The value of jointDir determines whether the rotation at the connected joint angle should be positive or negative based on the which limit of the initial joint angle was exceeded, upper or lower. In this case if the upper limit was exceeded then the rotation at the second joint angle will be negative. If the lower limit was exceeded then the rotation at the second joint angle will be positive. The connections structure for the test human model used when developing DEGAS is shown in table 5.4.

The basic update process can be seen in figure 5.13. When a high level control function affects a joint angle then its current value is assessed. This current value is made up from the low level contribution, all high level contributions and the Extra value for that joint angle. If the value is higher or lower than the constraint values then the process tests to see if a connection exists. If no connection exists then the joint cannot rotate further and is restricted to its constraint values. If a connection exists then the Extra value for the connected joint angle is updated according to the difference between the constraint value and what the joint angle would be without constraints. The connected joint angle will itself be checked against its limits using the same process. The connection structure allows movement to be passed up the structure, if needed, until no connection exists. At this point no further movement is possible in this direction.

Joint Angle		Connects To :-		JointDir
#1	BackRot1P	-	-	-
#2	BackRot1F	-	-	-
#3	BackRot1T	-	-	-
#4	BackRot2P	#1	BackRot1P	1
#5	BackRot2F	#2	BackRot1F	1
#6	BackRot2T	#3	BackRot1T	1
#7	BackRot3P	#4	BackRot2P	1
#8	BackRot3F	#5	BackRot2F	1
#9	BackRot3T	#6	BackRot2T	1
#10	BackRot4P	#7	BackRot3P	1
#11	BackRot4F	#8	BackRot3F	1
#12	BackRot4T	#9	BackRot3T	1
#13	NeckRot1P	#10	BackRot4P	1
#14	NeckRot1F	#11	BackRot4F	1
#15	NeckRot1T	#12	BackRot4T	1
#16	NeckRot2P	#13	NeckRot1P	1
#17	NeckRot2F	#14	NeckRot1F	1
#18	NeckRot2T	#15	NeckRot1T	1
#19	LeftAandSRotP	#12	BackRot4T	0
#20	LeftAandSRotF	#10	BackRot4P	0
#21	LeftMidSRotP	#19	LeftAandSRotP	1
#22	LeftMidSRotF	#20	LeftAandSRotF	1
#23	LeftArmRotP	#22	LeftMidSRotF	1
#24	LeftArmRotF	-	-	-
#25	LeftArmRotT	-	-	-
#26	LeftElbowRotF	#24	LeftArmRotF	1
#27	LeftElbowRotT	#25	LeftArmRotT	1
#28	LeftWristRotP	#26	LeftElbowRotF	1
#29	LeftWristRotF	#23	LeftArmRotP	0
#30	RightAandSRotP	#12	BackRot4T	1
#31	RightAandSRotF	#10	BackRot4P	1
#32	RightMidSRotP	#30	RightAandSRotP	1
#33	RightMidSRotF	#31	RightAandSRotF	1
#34	RightArmRotP	#33	RightMidSRotF	1
#35	RightArmRotF	-	-	-
#36	RightArmRotT	-	-	-
#37	RightElbowRotF	#35	RightArmRotF	1
#38	RightElbowRotT	#36	RightArmRotT	1
#39	RightWristRotP	#37	RightElbowRotF	1
#40	RightWristRotF	#34	RightArmRotP	0
#41	LeftHipRotF	-	-	-
#42	LeftLegRotP	#41	LeftHipRotF	1
#43	LeftLegRotF	-	-	-
#44	LeftLegRotT	-	-	-
#45	LeftKneeRotF	#43	LeftLegRotF	0
#46	LeftAnkleRotF	#45	LeftKneeRotF	1
#47	LeftAnkleRotT	#44	LeftLegRotT	1
#48	RightHipRotF	-	-	-
#49	RightLegRotP	#48	RightHipRotF	1
#50	RightLegRotF	-	-	-
#51	RightLegRotT	-	-	-
#52	RightKneeRotF	#50	RightLegRotF	0
#53	RightAnkleRotF	#52	RightKneeRotF	1
#54	RightAnkleRotT	#51	RightLegRotT	1

Table 5.4 Connection Structure for Test Model

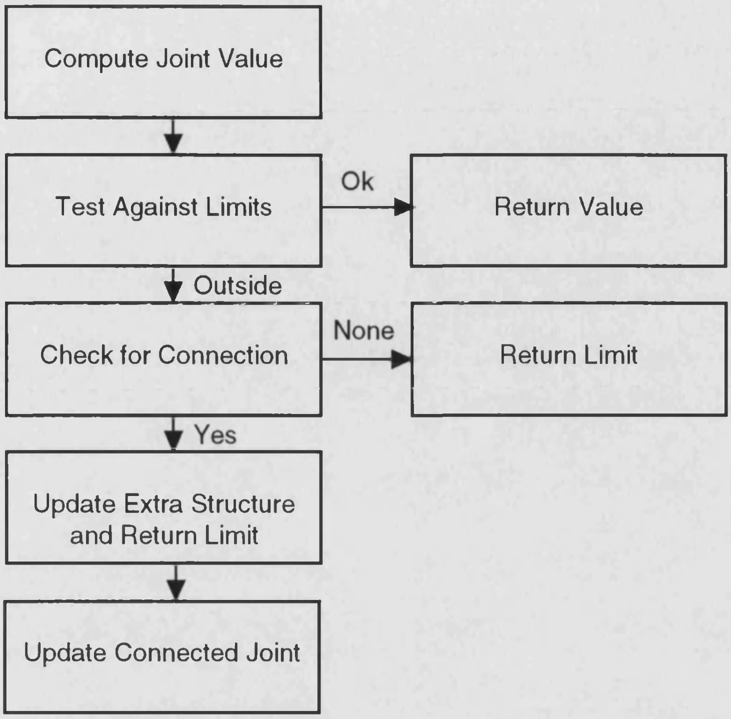


Figure 5.13 Update Process Using Connection Structure

For example, consider the movement of the wrist in the same direction as that of the elbow joint, see figure 5.14. If the hand rotated forwards to the left by a high level control function and it reaches its limit then the connection structure is used. The connection structure in this case, #28 *LeftWristRotP*, points to the Elbow joint, #26 *LeftElbowRotF*. So, this is passed the movement not possible at the wrist. If subsequently the limits of the elbow joint are reached then further use of the connection structure could pass the movement on to the stop arm joint, *#24 LeftArmRotF*.

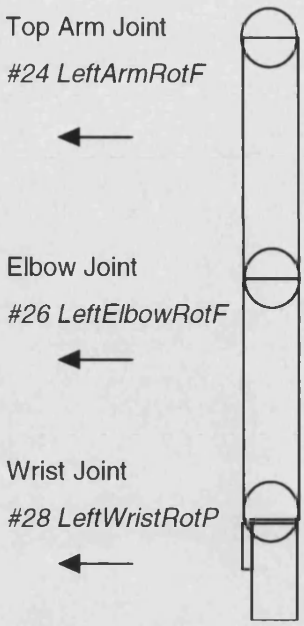


Figure 5.14 Wrist Movement Connected to Elbow and Shoulder Joints

5.4.4 Conflicts Between High Level Control Functions

Through the nature of high level control functions there can sometimes be conflict between what separate control functions are trying to achieve. For example the Shrug function can affect the arm joints, so what should happen if the Point At control function is then used? To solve these conflicts there exists a hierarchical structure which determines the order in which high level control functions are applied. In some cases the control functions can be used together with no unexpected results. In other cases some control functions can negate the effect of other control functions by taking precedence over them.

In general the goal directed functions, such as Turn Toward or Point At control functions are more important and hence take precedence over other control functions. This is because, as they are goal oriented, a specific objective should be met and is expected by an animator. Other high level controls are more general in nature, and their effects can be considered less important.

Table 5.5 shows the order in which high level control functions are processed in the various body groups. The list for each group is processed top to bottom, a later control function being able to override an earlier one if necessary. This does not mean that a later control function will override, however most functions can work together seamlessly.

Back and Head	Lower Back
	Raise Back
	Lower Head
	Raise Head
	Stance Open / Close and Forward / Back
	User 1-4
	Lean (Legs)
	Point At (LA) / (RA)
	Point At (BA)
	Turn Toward (WB)
	Look At
Arms and Shoulders	Shrug
	Negative Shrug
	Join Arms
	Stance Open / Close and Forward / Back
	User 1-4
	Point At (LA) / (RA)
	Point At (BA)
Legs and Hips	Join Legs
	Raise Leg (LL) / (RL)
	Raise Foot (LF) / (RF)
	Stance Open / Close and Forward / Back
	User 1-4
	Lean (Legs)
	Tip Toes
	Leg Point

Table 5.5 High Level Function Precedence Order

The Back and Neck group first applies the basic high level control functions of Lower and Raise Back and Lower and Raise Head. These control functions can work together very well. Even a mix of lowering and raising can work well if defined in a way that they do not automatically cancel each other out. Mixing back and head functions can also work well, providing separate head movement for better control. The Stance and User controls are such that they will only add to, or take away from existing posturing elements, not override them. So these movements can interact well with previous posturing methods. Lean (Legs) is again a simple addition to existing movements. The method makes more complex adjustments on the legs which will be discussed shortly. Finally the directed functions are applied at the end. As they have specific goals they may override earlier adjustments to the back and neck to achieve those goals. The Point At functions are applied first as they are primarily arm orientated movements, the arm movements of the control functions are applied after the back movements so the goals of the method may still be reached. The Turn Toward function is applied next which will ensure that the posturing elements of Point At and Turn Toward can work together. Thus pointing in one direction whilst turning in another is still possible. Look At is applied last as this is a neck function, so it can override any effect of the Turn Toward control function. This means that the figure can be made to turn in one direction and look in another.

The Arms and Shoulders group similarly applies the simpler control functions first. Shrug and Negative Shrug, Join Arms, Stance control and User control functions all can work together suitably. The arm Point At control functions are applied in specific order. First the left and right individual arm Point At control functions are applied. These are working on particular arms so should not effect each other, except for in the shoulder area. For this reason it is recommended that the animator be aware of this and have suitably defined Point At control functions if they are to be used together. The Point At (BA) control function is applied last and will override the previous Point At control functions for obvious reasons.

For the Legs and Hips group again the simpler control functions are applied first. Join Legs, Raise Leg (RL) / (LL), Raise Foot (RF) / (LF) and the global Stance and User controls, should all work suitably together. The remaining three control functions can all effect the global translation, to keep the feet on the ground, so must be applied last. Lean Legs is applied before Tip Toes so that the latter may be applied and be of effect. Point Leg must be applied last as it is goal directed and may override other control functions in this area.

5.5 DEGAS Information File Definitions

This section discussed what is contained in the DEGAS Information File and its primary uses. The file is of major importance to how DEGAS operates and is defined. It contains extra model information and allows the animator to control how the system interacts and operates on the figure. It provides the information which gives character to the model being animated.

5.5.1 What is Contained in the DEGAS File?

The DEGAS information file is an integral part of the animation system. It provides the animator with control over how a model is used in the system and provides the means for more varied use of the system. The implementation of these controls is through four sections within the DEGAS information file. There are controls and values for low level weighting, high level control function definition, constraint information and the underlying figure connection structure.

The reading of the DEGAS file by the program is such that it allows for comment lines in appropriate places by the user. If a line begins with a hash sign, #, then that line is ignored. There are a few restrictions placed on where these comment lines can occur however. In general comments are allowed at the start of the file, between major sections of the file and between high level function definitions. This allows the animators to make comments on the file in general and also label what particular sections of the file are, for ease of update and reading. Separation of values in the DEGAS file should be 'white space', either spaces or tabs. For more information on the format of the DEGAS file see Appendix A. The sample file contains comments in all applicable areas.

5.5.2 Loading and Use of DEGAS Files

When DEGAS is first run it expects, as a command line argument, information on the name of the DEGAS file to be used with the specified model. As default this can be done by simply specifying a name common to the model and associated DEGAS file. DEGAS then adds the appropriate file extensions to load the files. If, while using DEGAS, the animator wishes to use a different DEGAS file with the same model, then they may load one using the Load DEGAS button from the main control panel. This brings up a file selection widget from which the animator may select the file they wish to use. DEGAS then updates the postures being edited according to the new information. This can be useful when using a model with separate DEGAS files for specific situations.

5.5.3 Low Level Weighting

Low level weighting is used to give the animator definable and finer adjustment of low level controls. This is through simple weighting of the low level values from the posture information. These weights are defined in the DEGAS Information file as a series of ordered floating point numbers. The low level control sliders when using DEGAS are restricted to the range -1.00 to +1.00 in steps of 0.01 for simplicity. The default recommended value for a low level weight, excluding the back joints, is of magnitude 2.00. This provides a range of -2.00 to +2.00 in steps of 0.02 for low level control. Where finer control is needed the weight for individual joint angles can be reduced as required. This will reduce the range of the joint angle, but provide more exact and sensitive controls. It should be noted that low level controls are used in conjunction with high level control functions and thus the full range of movement allowed through constraints is not always necessary. No comments are allowed in the main body of low level weights.

5.5.4 High Level Control Function Definition

The information for high level control functions is provided in a similar way to the low level functions, an ordered list of floating point numbers. Commenting is allowed above each high level function so they may be labelled for ease of use. The back control functions, Lean, Side and Turn are defined in this section as, although they are not strictly high level, they are defined in a similar way. The difference being there is no definition of emotional interaction.

Simpler functions are defined by detailing the number of joints affected by the high level function, followed by the joints, the weights applied to them and the emotional interaction. All joints are referred to by their number, detailed in table 4.1 and figure 4.6 previously. Figure 5.15 shows an example definition of the Lean Back low level function. The comment '#Lean F' is ignored, here this indicates the Lean function operating on the back flexion joints. The number six indicates that six joints are affected, the maximum for this function. The joint numbers are specified followed by a weight for that joint.

```
#Lean F
6
2     1.0
5     1.0
8     1.0
11    1.0
14    1.0
17    1.0
```

Figure 5.15 Lean Back Low Level Function definition in the DEGAS File

After the definition of the low level back controls there is the high level function definition. Between each function definition there may be a comment, but the function should be defined in a specific order, detailed in figure 5.16. The functions should also be defined within the restrictions of their use, detailed in Chapter 6, High Level Control Function Definition.

```
#StanceOC    #StanceFB
#User 1      #User 2      #User 3      #User 4
#Lower Back #Raise Back #Lower Head #Raise Head
#Shrug       #Negative Shrug
#Join Arms
#Join Legs   #Lean Legs
#Raise Leg Left    #Raise Leg Right
#Raise Foot Left   #Raise Foot Right
#Tip Toes
#Turn Toward       #Look At
#Point At LA       #Point At RA       #Point At BA
#Point At Legs
```

Figure 5.16 High Level Control Function Definition Order

The more general high level control functions are defined in a similar style to the low level back controls, but also contain important emotional interaction information. Figure 5.17 shows a sample definition of the lower back function.

```
#Lower Back
6
2      0.1   -0.3  0.2   0.6   0.6   0.2   0.2   0.4   0.0
5      -0.2  -0.4  0.2   0.4   0.4   0.2   0.0   0.6   0.0
8      -0.15 -0.4  0.4   0.2   0.2   0.2   -0.4  0.8   0.0
11     -0.12 -0.4  0.6   -1.0  -0.2  0.2   -0.6  1.0   0.0
14     -0.1  -1.0  0.8   -1.0  -0.2  0.2   -0.6  1.0   0.0
17     -0.15 -1.4  1.0   -1.4  -0.2  0.2   -1.0  1.0   0.0
```

Figure 5.17 Lower Back Definition

The comment at the beginning is ignored, this is followed by the number of joints affected by the control function, in this case six. Following that there is the information on the actual joints affected and the interaction of the control function and emotional state. In this case the first number of each line is the joint angle and the first floating point number is the basic weight applied to it. The eight numbers following are weights linked to the eight basic emotions of the emotional state. The values found in the DEGAS file for each high level control function, and their use, are found in Chapter 6, High Level Control Function Definition.

5.5.5 Constraint Information

Constraint limit information for the joint angles are also detailed in the DEGAS file. These are listed as an ordered set of floating point values. The order is the same as the order of the joint angle numbering system, detailed in table 4.1 previously. An example of the constraint information is shown in figure 5.18. The formatting is not necessary, though can help with ease of reading and update. For each joint angle there are the lower limits of pivoting, flexion and twisting where applicable, followed by the upper limits.

```
#Constraint Info
-1.0        -1.0        -1.0        1.0         1.0         1.0
-1.0        -1.0        -1.0        1.0         1.0         1.0
-1.0        -1.0        -1.0        1.0         1.0         1.0
-1.0        -1.0        -1.0        1.0         1.0         1.0
-1.0        -1.0        -1.0        1.0         1.0         1.0
-1.0        -1.0        -1.0        1.0         1.0         1.0
-0.175      -0.088      0.175       0.088
-0.175      -0.263      0.175       0.35
-0.525      -0.788      -1.575      3.15        3.4         1.575
0.0         -0.788      2.8         1.575
-0.788      -1.575      0.788       1.575
-0.175      0.175
-1.225      -0.788      -0.788      1.225       2.8         0.788
0.0         2.8
-0.875      -0.525      1.313       0.525
```

Figure 5.18 Sample Constraint Information from DEGAS File

5.5.6 Underlying Figure Structure Information

The Underlying Figure Structure of the model is detail in the last section of the DEGAS information file. The information is ordered by joint angle, containing two integers for each. The first integer represents the joint angle connected, and the second is the *jointDir* value indicating the direction of the joint connection. Figure 5.19 shows a sample from a DEGAS file. The format is used to separate the individual joints, each made up of up to three joint angles representing pivot, flexion and twisting. For example the first line represents the lowest back joint where no connections exist. The second line represents the next back joint rotations. These is connected to the appropriate lower back joint rotations, #1, #2 and #3. In each case the joint rotation is positive, hence the *jointDir* value is one.

```
#Connection Info
0       0       0       0       0       0
1       1       2       1       3       1
4       1       5       1       6       1
7       1       8       1       9       1
10      1       11      1       12      1
13      1       14      1       15      1
12      0       10      0
19      1       20      1
22      1       0       0       0       0
24      1       25      1
26      1       23      0
12      1       10      1
30      1       31      1
33      1       0       0       0       0
35      1       36      1
37      1       34      0
0       0
41      1       0       0       0       0
43      0
45      1       44      1
0       0
48      1       0       0       0       0
50      0       52      1
51      1
```

Figure 5.19 Underlying Figure Structure DEGAS File Information

5.6 Use of Traditional Animation Techniques

This section discussed the use of traditional animation techniques within just the posturing system.. Other techniques, such as timing and anticipation, are covered in the Animation Implementation chapter. Methods which may be utilised in the posturing system include exaggeration and secondary action. Also discussed in this section is the use of artistic techniques, such as composition and colour. These methods are further developed in the Animation Implementation chapter. The discussions in this section are based on what is possible in the DEGAS posturing system as it stands, and what is possible using the system as a basis. Due to time constraints some techniques are not fully implemented in the system as it stands.

5.6.1 Exaggeration

Exaggeration is commonly used by animators to make a point more clearly, to draw the viewers attention to the message being put across. It is generally an extreme posturing element, one not done under normal circumstances. Hence it is a popular technique in cartoons and related animation where realism is not of paramount importance. However, while it might not be used under normal circumstances it still has benefits in more realistic animation when applied in a more subtle way. The method is used by real people for the same reasons as animators might use it, to draw attention to, or emphasis, a point. For example, someone who is sad may lower there back and head, this would normally convey sadness to another person. However if they wish to make a point of the fact they are sad they may exaggerate these movement to bring it to the direct attention of the other person. The shoulders can drop, the head and back can come down lower, this leaves the second person in no doubt that the first is sad or upset about something.

There are three methods and techniques for employing exaggeration within DEGAS using the posturing system. By increasing the value of a particular high level function, by increasing the interaction of a high level function in a particular area or by increasing the values of the emotional state of the figure. The first two methods are similar but the control provided by the second is greater but more complex to achieve.

When using high level control functions to posture the figure the range of values possible for the main controlling value is usually between -1.00 and +1.00 or 0.00 and +1.00. These ranges provide a uniform set of ranges for most control functions. In normal use the values are best set between 0.00 and +/-0.75, dependant on the control function. When values greater than these limits are used then exaggeration can occur naturally. The nature of definition of the various high level functions may mean that some fine tuning is needed, but this method is a quick and easy way to exaggerate all or part of a posture.

An example of this method is shown in figure 5.20. There are three pictures each with the Negative Shrug control function applied and a Sad emotional state. In the first the value of the control function is 0.1, a small drop in the shoulders. In the second picture the value is 0.3, here the drop is significant but still within reasonable movement for normal motion. The final picture has a value of 0.75 and shows exaggeration. Here the shoulders are dropped dramatically beyond the range of normal movement.

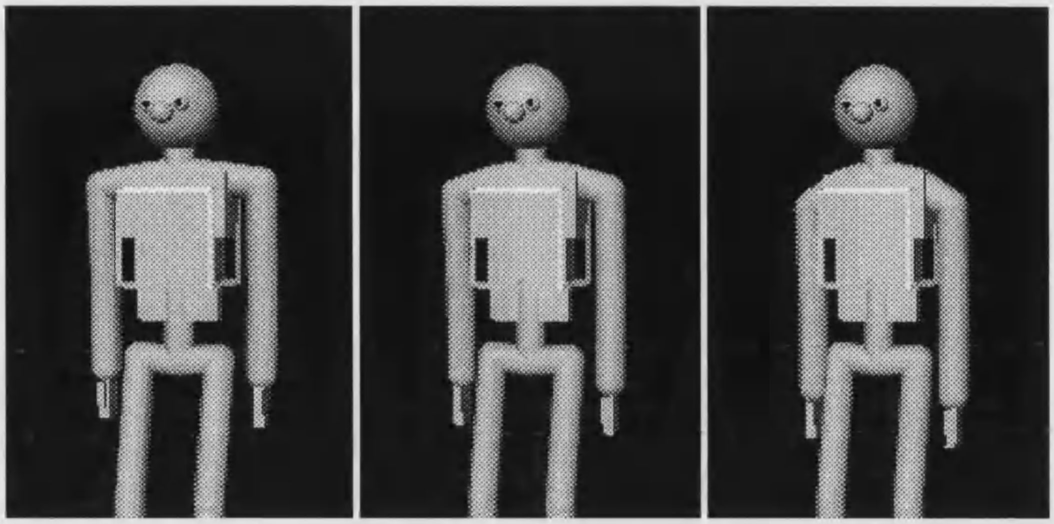


Figure 5.20 Sad Negative Shrug With Values 0.1, 0.3 and 0.75

The user interaction with how high level control functions are used and defined provides a more flexible method of exaggeration. The previous method relies on the definition and interaction of the particular high level control function being suitable for that method. With this technique the animator can define the high level control function to work suitably. More over it is possible to target the exaggeration not just with the limits of individual high level control functions but to individual elements of those control functions. For example if using the Shrug high level control function. Using the first technique the exaggeration would effect the shoulders and arms in the same way the normal function would. Using this second technique the animator could define the interaction to be such that the exaggeration affect certain joints more, as could be the case. The draw back of this technique is that it is more complex for the animator to carry out. Though the animator may define a separate DEGAS information file more suited to exaggeration and substitute this for the regular file when needed.

The final method for exaggeration produces a more general effect, but in analysis is a more natural and suitable method. By increasing the values of the emotional state of the character the resulting changes to the high level control function interaction will produce exaggerated effects. The effect will of course affect the entire figure rather than being area specific like the previous techniques. There are advantages to this method however, a change to more intense, or high valued, emotional state is a more natural way at looking at the causes of exaggeration. The animator is creating the cause of the exaggeration rather than simulating the final effects. This method requires well defined and structured interaction between the emotional state and the high level control functions. This technique can also be used in conjunction with the second method to provide a less general approach and utilise greater localised interaction between animator input and program output.

Figure 5.21 shows a figure again with Negative Shrug applied. This time the value of the control function is kept constant at 0.5, but the emotional state is varied. In the first picture the emotional state has a Sadness value of 0.1. In the second picture this is increases to 0.4 and in the final picture it is 0.75. The effect is similar to that of the other examples, but there is a more intuitive feel to its application.

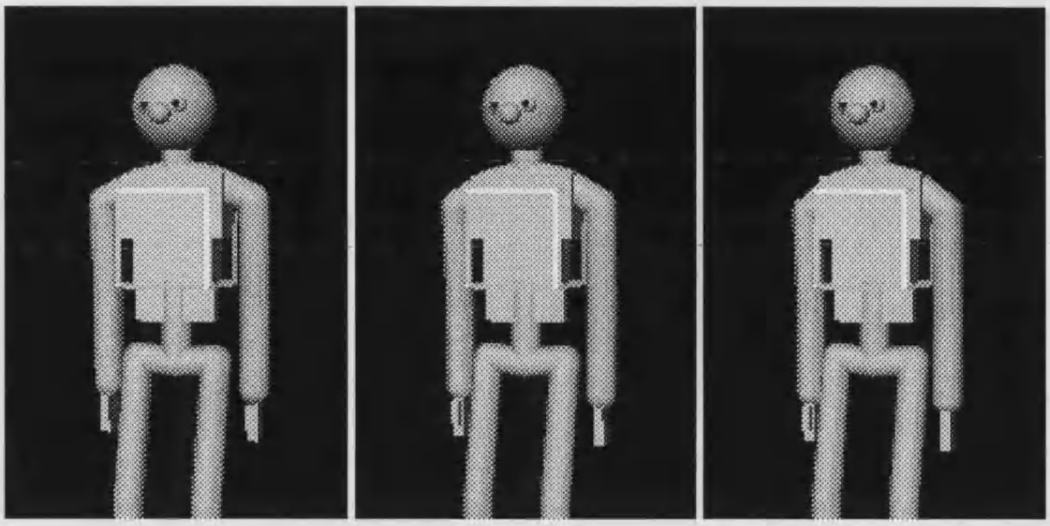


Figure 5.21 Negative Shrug Applied With Sadness of 0.3, 0.5 and 0.75

5.6.2 Secondary Action

Secondary action is a resulting action caused by a primary movement. A typical example being the use of the arms to balance a primary movement. The use of secondary movement by an animator can help re-enforce a primary movement. Automatic generation of the secondary movement can aid the animator by providing the initial movement which can be fine tuned to the requirements. However it is important to realise there are situations where secondary movement will not be desired so it should be an option rather than an inherent feature of the posturing system.

DEGAS can produce secondary action through the use of the definition of high level control functions. This currently limits the areas of secondary action to those affected by the particular high level control function, but this still allows a wide range on possibilities. Figure 5.23 shows a simple example of this. The motion created is the raising and movement forward of the right hand, as an offer to shake someone's hand. This is accomplished by the adjustment of joint angles 35 and 37. The high level control is also linked to joint angles 24 and 26, the corresponding left arm joints. The negative weight on joint angle 24 causes the arm to be brought back as the right arm is brought forward as secondary action similar to that described and illustrated in Section 3.2.4. The emotional interaction is not implemented in this example.

```
#User 3
4
24     -1.0  0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
26     1.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
35     2.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
37     1.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
```

Figure 5.22 High Level Control Function Definition Utilising Secondary Action

5.6.3 Composition

The use and understanding of composition in relation to the posturing system is an important part of the animation process. The key frames of the animation represent important stages in the an animation, so care should be taken that the composition at these points compliments the feeling and mood required.

Currently in DEGAS there is very limited definable control over the composition or camera control. The standard features of the Open Inventor viewing window allow user manipulation of the viewing position, but DEGAS does not store this information as posture specific. Hence a change in the viewpoint will affect all postures currently being edited.

The controls provided by the standard Examiner Viewer allow the animator to adjust the position of the viewpoint, zoom in and out, and seek objects or points, see figure 5.23. To control the viewing position the animator may use the mouse pointer in the viewing window. The mouse must be in viewing mode, not picking mode, to use these features. By holding down the right mouse button the animator may change pointer modes and other viewing preferences. If the left mouse button is depressed then movement of the mouse will rotate the camera about the scene in a track-ball motion. Through this method it is possible to view the model from any angle and orientation. If the middle mouse button is depressed the animator may move the mouse up, down, left or right to adjust the translation of the camera in the view window plane. If the left and middle mouse buttons are depressed then the animator may move the mouse up and down to adjust the zoom. The rotation and zoom aspects of the viewing position may also be adjusted by using the wheel sliders positioned around the viewing window. These are labelled Rotx, Roty and Dolly, see figure 5.23.

Of the icon set on the right hand side of the viewing window there are two useful composition functions. The View All button will zoom out the viewing position to ensure all objects in the scene graph are visible. This happens instantaneously when the button is pressed. The Seek button is used to centre the view on a particular object or point. Once selected the mouse pointer will change to a target pointer which can be used to "pick" in the main viewing window. This can also zoom into or out of the view depending on the preference settings. The preference settings are accessed through the pop-up menu when the right mouse button is pressed. Here the animator my define whether the Seek function works on points or objects and the zoom factor used when seeking.

Figure 5.23 Examiner Window

Compositional balance in important in allowing the viewer to see what the animator is trying to show, rather than be distracted by poor compositional elements. The effective use of balance can re-enforce expressed emotions to produce a more complete effect. [49]

Basic rules can be applied to the setting of key frames to help create the overall effect desired by the animator. To begin with all that the animator wants to show the viewer must be inside the frame. This may sound obvious, but there are significant points relating to this. The edges of the frame are important in that they are the limits of what the animator is showing to the viewer. These limits need to cut the scene at an appropriate point, or the viewer will be distracted by what they can, or can not, see. Figure 5.24 shows a frame containing simple basic objects, a rectangle, a triangle and a circle. The triangle is suitably positioned, but the rectangle and circle are examples of poor composition. The rectangle is not important and barely in the frame, this distracts the viewer by causing them to wonder what it is. The circle is mostly in the frame but one part is just on the right hand edge. This is distracting to the overall composition of the picture. These are basic examples but illustrate some of the principles of good composition.

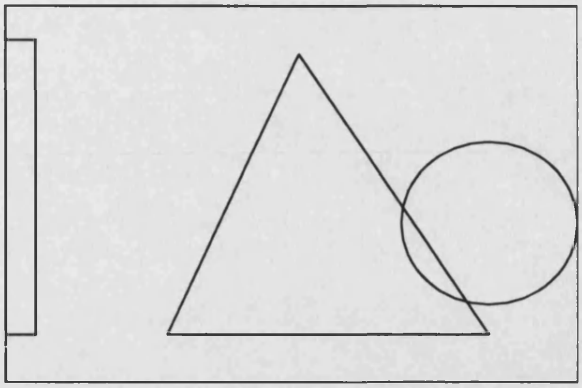


Figure 5.24 Frame Containing Poorly Composed Basic Objects

This sort of compositional adjustment could be handled by letting the animator specify the importance of objects within the scene and then automatically adjusting the camera to allow for them. By using the Inventor functions to calculate the bounding boxes of the important objects and projecting their positions onto the viewing plane the composition could be generated by minor adjustment of the zoom and direction of the camera. Restricting the adjustments made automatically the essence of the original composition could still be maintained.

Balance is an important part of composition. It is a necessary component of artistic communication, as without some balance the message can become lost in the confusion of composition [49]. Most techniques of balance are difficult to realise automatically in a system such as DEGAS. The development of balance relies on artistic talent and instinct for a large part. There are however some techniques which are possible to utilise and methods which can help determine how the balance is expressed. The expression of balance is of particular importance to DEGAS, as it is possible to use the balance of the frame to re-enforce emotional messages.

One technique popular with artists during the Renaissance is called the Golden Section. Instead of centralising the point of interest in the frame it is moved to just off centre at a calculated balance point. The line was found to be very pleasing to the eye, a natural balance point. Figure 5.25 shows the approximate vertical position of the line from the left hand edge. It is calculated by making the ratio of the longer section to the overall length is equal to the ratio of the shorter section to the longer section. That is the distance AB is such that AB/AC = BC/AB.

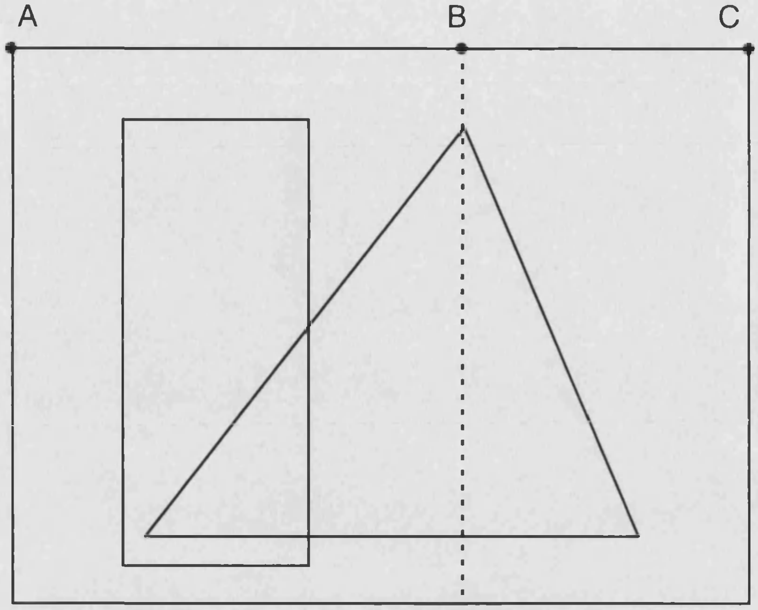


Figure 5.25 The Golden Section

Using simple algebra this can be calculated as approximately 62% of the total distance. It is also possible to further subdivide the frame further by applying the golden section horizontally on the sections created by the first line, and further more by applying once again vertically. In some examples of Renaissance art the Golden Section defines all major vertical and horizontal lines in the picture.

The use of composition to enhance emotional expression can be a useful tool to the animator. The viewing point and centre of interest can be used effectively to re-enforce emotional elements in a posture. An important part of emotional expression through the body is that emotion is usually expressed more through certain areas of the figure. This is useful to the animator as it is possible to make the important area associated with an emotion the centre of interest. This brings the significant elements of the posture to the attention of the viewer. For example, in figure 5.26 there are two pictures each of the same posture, a figure in a sad emotional state. The first shows the figure from a common straight on angle with the figure central in the frame. In the second the emotionally specific posturing elements are made more prominent by turning the figure to show the lowered back and shoulders more clearly. The viewpoint is made closer and centred on the back to further direct the viewers eye to the points of interest. These simple compositional changes have enhanced the frame to make the second figure look sadder than the first, whilst keeping the actual posture the same.

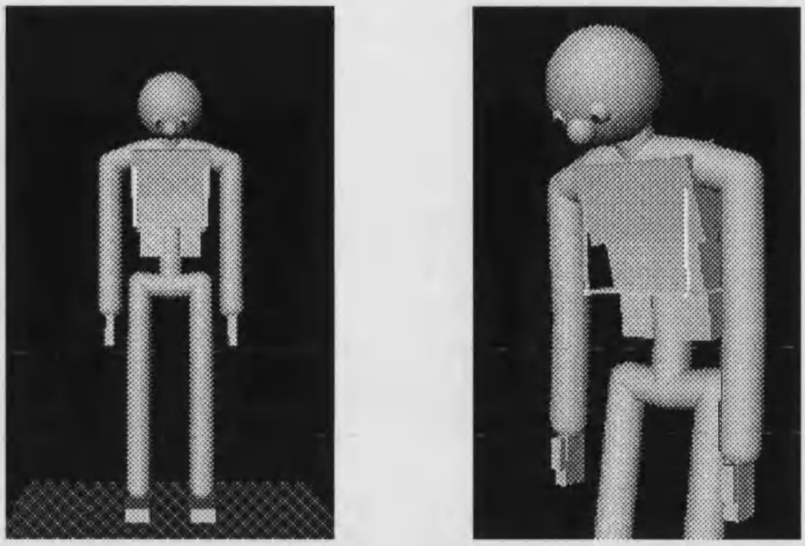


Figure 5.26 Compositional Changes Enhancing the Feel of an Individual Frame

Control of the angle of view can also be used to enhance emotional messages and convey relational status between the viewer and the figure. By changing the viewpoint from looking on the same level as the figure to a point above or below the animator can enhance emotional interaction. Dependent on the emotional state of the figure this can cause the figure to look submissive and accepting or more dominating. Figure 5.27 shows two pictures of a happy and confident figure. The first is viewed at the same level as the figure, in the second the viewpoint is moved to look up at the figure. The effect is to make the figure more dominating and imposing, the confidence becomes closer to arrogance.

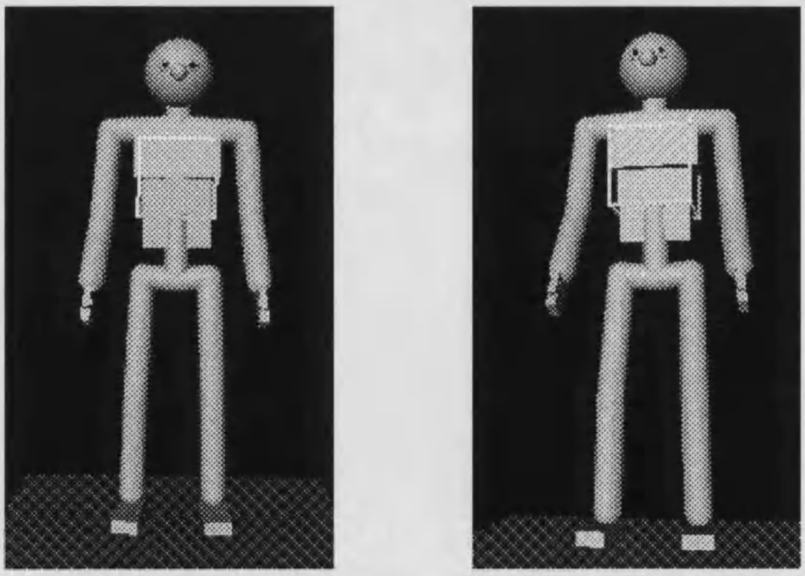


Figure 5.27 Change of Viewpoint Enhancing the Feel of an Individual Frame

Figure 5.28 shows the same sad posture as used in figure 5.26 previously. Here the posture is viewed from below and again the feeling is enhanced. The figure is not imposing as before because the emotion being expressed is different. This time the effect is to make the viewer sympathise with the figure, the view is looking more toward the face of the model. These examples demonstrate the varied and dramatic effect of changing the viewpoint in the posturing system. When these techniques are applied to animation the effect can be even more dramatic, this is discussed in the Animation Implementation section.

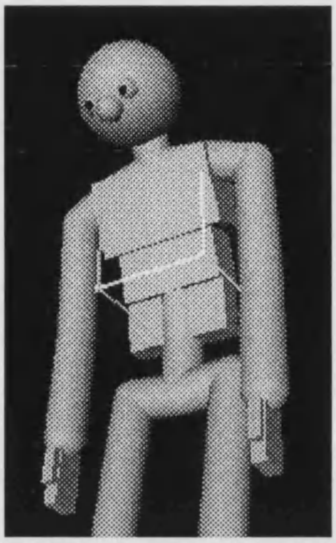


Figure 5.28 A Similar Change of Viewpoint Applied to a Different Emotion

5.6.4 Colour

Colour use in animation can have useful applications in terms of emotional interaction with the viewer. Colour theory is well documented in design and more traditional artistic techniques. Colour adjustment is not fully implemented in DEGAS, but there are methods for limited control available. Discussion will first examine the effects of colour with respect to emotions and then examine the methods available to use these techniques.

Figure 5.29 shows the composition of the colour wheel in terms of primary colours and secondary colours. The primary colours being red, blue and yellow, and secondary colours purple, orange and green. The secondary colours are made up by mixing the two adjacent primary colours. For each of the primary colours there is a corresponding secondary colour called its complementary colour. These are determined by looking at the colour opposite on the wheel. So for red it is green, for blue it is orange and for yellow it is purple.

It is worth noting at this point that when composing colours on a computer it is common to work in terms of mixing light rather than using the classic colour wheel. Colours are commonly represented in terms of the three primary light colours, red, green and blue.

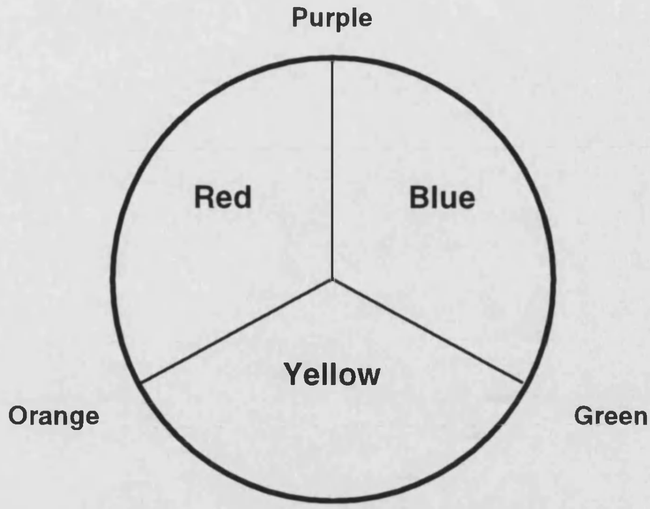


Figure 5.29 Colour Wheel

Looking at basic colours in terms of emotions is difficult because there are many cultural complications involved in what a colour represents to different people. The use of subtle colour changes, such as adding a hint of red, is still valid in a universal system. There are common emotional elements to the colours which can be used in this way. I will first cover briefly the primary and secondary colours in terms of general feeling, then go on to discuss the basic emotions used by DEGAS in relation to these.

Red is a colour of warmth and passion, and as such can also be associated with strength of feeling, anger, and warning. Blue when used alone is a cool colour, though when mixed can change dramatically. It is associated with the sky and sea, freedom and calm. It is a passive colour compared to the activity of red. Yellow is golden and has the lightest feel of the primary colours, it can be bright when contrasted with subtler colours. Purple is a colour which can be warm or cold depending on the amounts of red and blue used. It commonly represents mystery or power. Orange is a warm colour, the colour of fire and associated with the warm browns of earth. Green is a cool colour, associated with plants and hence life and the peace of nature. Green can also represent illness and discomfort when weaker hues are used. [50, 51].

Joy is a warm and often vibrant feeling, so colours which reflect this such as reds, oranges and strong yellows can be used to enhance this emotion. Sadness is a cold feeling, so the cooler colours blue, green and subtler purples can be used here. Acceptance is a warm and embracing emotion, but it is also quite calm and peaceful. Colours which are useful here are the warmer shades of blue and green and some subtler reds. Disgust can be a strong passionate emotion, so the use of stronger reds and purples can be useful. For more subtlety weaker greens can be used. Anticipation and Surprise can be vibrant and are well suited to brighter colours. Depending on the complex emotions these can be mixed with other colours representing the other mixed emotions. Fear and Anger can both used similar strong colours, red and purple are especially effective. [50, 51].

As DEGAS stands there are two methods by through which the animator can make use of colour in the posturing system. Both make use of the Inventor model definitions and how DEGAS uses them. The first option is to use material nodes in the Inventor scene graph, the second option is the use Inventor lighting nodes in the scene graph. Alternatively a combination of the two can be used. When DEGAS interprets the scene graph of a model it expects and requires certain nodes to be named and positioned correctly. However, it is possible to add extra Inventor nodes, such as material and lighting nodes, which are ignored by the DEGAS system but interpreted by Inventor. Due to time constraints interactive control between the posturing system and the added nodes is not yet possible.

A Material node can be used to define the display qualities of nodes in the scene graph. It works in a similar way to transform nodes in that its effect is only on nodes to its right and lower in the scene graph. This means individual objects in the model can easily be coloured to suit the requirements of the animator. A Material node contains the following fields:

- **ambientColor** Stored as an Inventor colour, a one dimensional array of three floating point numbers representing the colour using the RGB colour model. It defines the reflected colour of an object in response to the ambient light. Default value [0.2, 0.2, 0.2]
- **diffuseColor** Stored as an Inventor colour. This defines the objects base colour. Default value [0.8, 0.8, 0.8]
- **specularColor** Stored as an Inventor colour. This defines the reflective quality of an objects highlights. Default value [0.0, 0.0, 0.0]
- **emissiveColor** Stored as an Inventor colour. This defines the colour and intensity of light produced by this object. Default value [0.0, 0.0, 0.0]
- **shininess** Stored as a floating point number. This defines the shininess of the objects surface, within the range 0.0 to 1.0. Default value 0.2.
- **transparency** Stored as a floating point number. This defines the transparency of the objects surface, within the range 0.0 to 1.0. Default value 0.0.

An example of a Material Node in a model definition is shown in figure 5.30.

```
DEF LeftEyeColour Material {
      ambientColor      0 0 0
      diffuseColor      0 0 0
      specularColor     0 0 0.8
      emissiveColor     0 0 0
}
```

Figure 5.30 Material Node Definition

The lighting nodes available under Inventor are more extensive. A base abstract class SoLight defines the basic class containing three fields:

- **on** Boolean flag, whether the light is on or not.
- **intensity** Floating point value, ranging from 0.0 to 1.0.

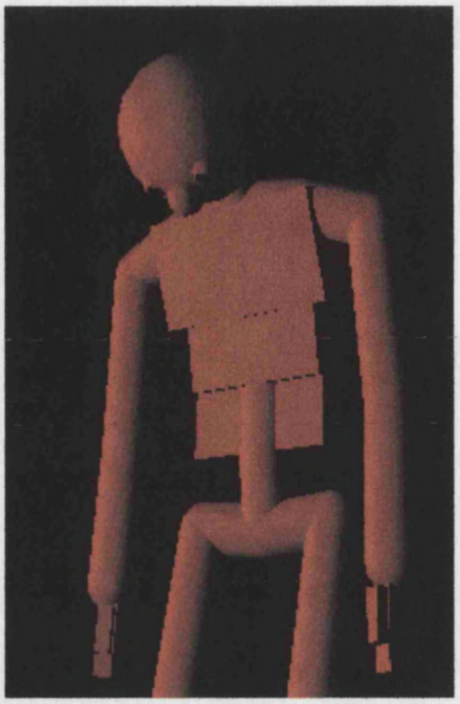
- **color** An Inventor colour value, defining the colour of the light.

There are three subclasses contained by SoLight, SoPointLight, SoDirectionalLight and SoSpotLight. A SoPointLight is represented by an extra field giving the location. This light illuminates in all directions from this location equally. A SoDirectional light adds an extra field defining a direction. It illuminates uniformly in that direction, and is not defined by a location. A SoSpotLight has a location, a direction, a drop off rate and a cut off angle. These help define a theatrical spotlight which has a definable area of effect. The lights can be placed in the scene graph in a similar fashion to the material node. To manipulate the values of the lights Inventor provides manipulators.

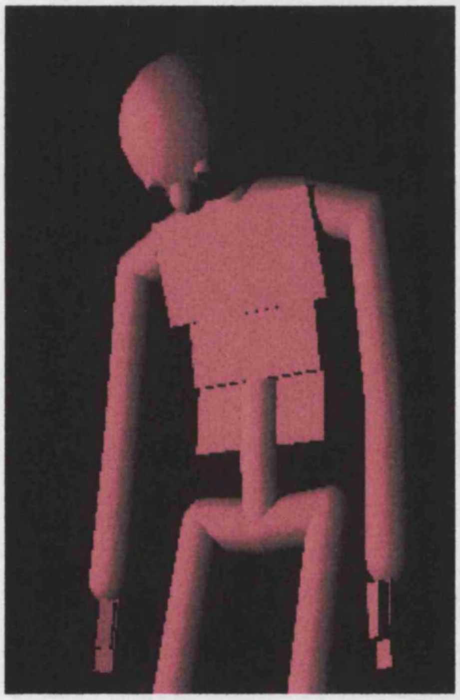
The methods of Material nodes and Lighting nodes can be used to great effect together to produce good colour combinations. By giving the objects one colour and shining a light of another colour on it you can cause enhanced effects. The mixing of complementary colours can be used to create a bold contrast in colour, as the pairings are such that each brings out the others colour.

A set of basic examples can been seen in figure 5.31. The posture is similar to that used in figure 5.28, but in each case a different colour was used to light the figure. The spot light used also enhances the general feel of the posture as it adds deeper shadow. In Picture A a deep blue is used and this is complimentary to the sadness of the posture. This re-enforces the feeling expressed. In Picture B a deep red is used and here the colour gives off signals of anger. This give more information about the feeling being expressed by the character. This is helpful in the case of anger as it can be difficult to express in a static pose. Pictures C and D are useful to compare to the more obvious colour effects of the Pictures A and B. Picture C uses a generally warm colour to light the figure, though not as harsh as the red of Picture A. This has the effect of lessening the feeling of sadness expressed by the figure. Picture D uses a neutral colour and is helpful in using to compare to the other pictures. While these examples use quite a wide various of colour it is obvious that they can have a powerful effect on the feeling of a posture, and the messages given to the viewer.

Picture A



Picture B



Picture C

Picture D

Figure 5.31 Colour Use Examples

Chapter 6 High Level Control Function Definition

6.1 General High Level Control Function Issues

This chapter discussed in-depth the individual high level control functions implemented so far in DEGAS. It examines the definition and use of the control functions and the methods behind them. The emotional interaction is discussed in relation to how each is defined in the DEGAS information file, and what controls exist for the animator to adapt them.

The use of high level control functions is through adjustment of parameters with sliders and Inventor manipulators where applicable. The sliders are generally restricted to a set range, either 0.00 to +1.00 or -1.00 to +1.00, adjustable in steps of 0.01. The restrictions are made for several reasons. The adjustment tools are designed to be simple and easy to use. Small and continual adjustments can be made with constant updating of the model and visual feedback. This is essential for the animator to see what effect the adjustment they are making is doing. This has to be balanced with the constraints of what is possible through graphical restrictions and the use of Motif widgets. A compromise between precise control, small adjustment steps, and size of slider controls has been made. The restrictions of the possible ranges can be countered by the definition of the high level control functions. This means that the animator can tailor the range of the controls to suit the range of the control effects. The drawback to this approach is that as the range of model movement is increased, the level of precise control is reduced. Taking a simple example, if a high level control function adjusted a joint angle on a straight value basis then an adjustment of 0.01 in the control function value would correspond to a 0.01 adjustment in the joint angle. This method restricts the joint angle to the relevant range of the slider, with a maximum value of +1.00. If the animator wanted a larger range for the joint angle they could weight the control function value by a factor of 2.00. This would make the maximum value of the joint angle 2.00, but the corresponding minimum step adjustment is 0.02. This is considered acceptable as the greater range of movement in a joint angle will generally mean less precise control is needed. If further precise control is required then this can be provided by low level adjustment.

For some high level control functions the slider controls are complemented or replaced by Open Inventor manipulators. The use of these Inventor tools is in areas where it is felt that a visual reference in relation to the model is needed. The manipulators are displayed in the viewing window in relation to the model being animated and can be adjusted in a similar way to normal slider adjustment. The main use of these manipulators is with directed high level control functions, discussed in the next section.

6.1.1 Definition of Interaction for General High Level Control Functions

For the simpler high level control function there exists a general definition of interaction between the control function value, the emotional state and the joint angle effects. This is best explained by example. Figure 6.1 shows the definition of a general control function and specifically the Lower Back function, from the DEGAS Information File.

```
#Function Name
<no. of joint angles, n, affected>
<joint angle 1 ref.> <weight> <emotional weights>
      .
      .
      .
< joint angle n ref.> <weight> <emotional weights>

#Lower Back
6
2     0.1   -0.3  0.2   0.6   0.6   0.2   0.2   0.4   0.0
5     -0.2  -0.4  0.2   0.4   0.4   0.2   0.0   0.6   0.0
8     -0.15 -0.4  0.4   0.2   0.2   0.2   -0.4  0.8   0.0
11    -0.12 -0.4  0.6   -1.0  -0.2  0.2   -0.6  1.0   0.0
14    -0.1  -1.0  0.8   -1.0  -0.2  0.2   -0.6  1.0   0.0
17    -0.15 -1.4  1.0   -1.4  -0.2  0.2   -1.0  1.0   0.0
```

Figure 6.1 General and Lower Back Definition from DEGAS File

The general definition gives the format of a basic high level control function. The name is given as a comment at the top. This is followed by the number of joints affected by the control function. In the case of Lower Back this value is six. Dependant on the high level control function this value is restricted to 10, 20 or 55 joint angles. This allows for control functions with small, medium and global effect. Following this there are the joint angle interaction definitions, each line representing one joint angle. The first number gives the joint angle affected, using the numbering system as specified in table 4.1. The second number gives the basic weighting applied to the angle by the control function. For Lower Back the first joint angle affected is number two, Back Rotation 1 Flex, and the basic weight is 0.1. The weighting given is suitably adjusted according to the low level weighting applied to that joint, thus a positive weight relates to a positive low level rotation for that model. The remaining eight values represent the weights for the eight basic emotions of the emotional state. To calculate the effect at a particular joint angle of a general high level control function the formula given in figure 6.2 is used, where C is the contribution, v is the high level function value, w is the basic weight, and E_n and e_n are the emotional state values and emotional weights respectively.

$$C = v.w.(1 + \sum_{n=1}^{8} e_n E_n)$$

Figure 6.2 Formula for General High Level Control Function

So for example if the value of Lower Back was 0.5 and the emotional state was set at (0.5, 0.0, 0.0, 0.3, 0.3, 0.0, 0.0, 0.0) then the effect on back rotation 1 flex would be :-

0.5 * 0.1 * (1.0 + (-0.3 *0.5) + (0.6 * 0.2) + (0.2 * 0.2)) = 0.0505

The basic weight, w, defines the fundamental movement at that joint angle by the particular high level function. If the emotional state is defined as (0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0) then the formula becomes simply $C = v.w$. Thus with no emotional interaction the effect of a high level function at a joint angle is the value of the high level function modified by the corresponding basic weight. The formula is structured so that the general movement, as defined by the animator, is carried out with the emotional state acting on that movement. It is not intended that the emotions alter the essence of a motion, more that they control how that motion is carried out. So for example if the Shrug high level control function is defined such that the arms lift up as well as the shoulders in a Gallic shrug like fashion, then the emotional interaction should not alter this such that it becomes indistinguishable from the intended movement.

The emotional state interaction is controlled by the eight emotional weights defined for each affected joint angle. The individual values specify the interaction of each basic emotion, defined in the emotional state, on the basic effect of the high level function. If the value is positive it makes the overall effect of the high level function on that joint angle greater. If the value is negative then it reduces the overall effect of the high level control function on that joint angle. If the value is less than -1.0 then the emotional effect could reverse the basic effect of that high level control function. As will be shown in examples throughout this section, this use is rare as it can alter the basic nature of the defined high level control function. In general these value are kept to the range -1.0 to +1.0. The low range -0.3 to +0.3 gives a mild effect. The middle ranges -0.6 to -0.3 and +0.3 to +0.6 give a medium effect. Values in the high ranges -1.0 to -0.6 and +0.6 to +1.0 have a large effect. Values outside these ranges result in a large effect and should be used with caution.

6.1.2 The Directed Control Functions

There are six functions implemented in DEGAS which can be considered as directed control functions. That is, they have a direction or goal toward which the posturing control is aimed. These are the Look At, Turn Toward (WB), Point At (BA), Point At (LA), Point At (RA) and Leg Point functions. With each of these functions there is a similar interface for the animator. This consists of a control panel, containing sliders and button controls, and an Open Inventor Point Dragger. The control panel, see figure 6.3, contains a slider to vary the degree to which the function is carried out, a toggle switch and a push button. The toggle switch is simply a flag to check when the animator wishes to use the function. If it is checked then the function is used, if it is blank then it is not used. The push button is connected to the Point Dragger. The Point Dragger is displayed in the model viewing window, and it is used to determine the direction of movement, or goal, of the high level control function. As there are six possible control functions which use the Point Dragger the push button, labelled Focus, is used to switch the Point Dragger to the position representing the particular control function. So, if the Focus button is pushed in the Look At control panel, then the Point Dragger is positioned at the value corresponding to the Look At control.

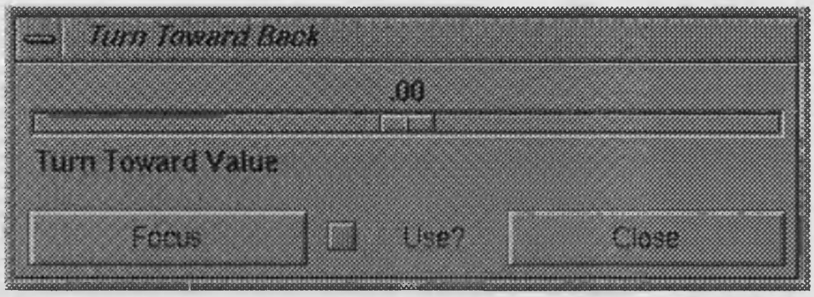


Figure 6.3 Directed Control Function Sample Control Panel

The Point Dragger is a useful tool for setting a position relative to the figure as it is displayed in the same view. Figure 6.4 shows some close ups of the dragger and how it can be used. To grab the dragger the mouse pointer must be in picking mode. This is entered by simply clicking on the mouse pointer icon on the right-hand side of the view window. When in this mode the animator can click and hold the left mouse button on either of the two elements on the dragger, the cylinder and flatten box shown in the first picture in figure 6.4. The cylinder controls the vertical Y-position of the dragger. The flattened box controls movement in the X-Z plane. The second two pictures in figure 6.4 show the results on clicking on these two elements. Helpful arrows appear which show the direction of movement on the dragger. Movement is then achieved by keeping the left button depressed and moving the mouse in an appropriate direction.

Figure 6.4 Open Inventor Point Dragger

6.1.3 The Move to Floor Control Function

There is a control function in DEGAS which can automatically adjust the translation of the model to make foot contact with the floor. This is a useful method to adjust the figure once the legs or translation have been adjusted. It is not strictly a high level function, in that there is limited user control over the interaction and no emotional data is used in the process. Access to the function is through a simple button press in the Global Controls panel, see figure 6.7 later in this section. The same function which performs the adjustment in the posturing system can also be utilised in the animation system to adjust translation automatically during an animation. This is discussed in greater detail in Section 7.4.8.

The process of adjustment uses some of the built in Open Inventor functions which search and query values in the scene graph. The pipeline process of the function is detailed in figure 6.6. First the set-up initialises the Inventor Search and Bounding Box actions. These can be used in conjunction with each other to search for named scene object nodes and get information on their global position. The Search action is used to locate the left and right foot nodes, which are represented by simple boxes in the standard testing model. The paths to the foot nodes found by the Search action are used by the Bounding Box action to gain the information on their global position. Most important in this case is the minimum Y position which indicates the relevant foot's lowest position. Finally the information for each foot is compared to find the lowest of the two and the Global Translation of the figure is adjusted accordingly.

The effect of using the function can be seen in figure 6.5. The first picture shows the figure before adjustment, the second picture after the function has been applied. The function as it stands also adjusts the Z translation value of the figure, the forward and backward movement. This means that the figure maintains its foot position on the floor accordingly under normal leg adjustment. This method is more useful when applied in the animation system as it prevents "moon-walking" of the figure during walk cycles, see Section 7.4.8 for more details.

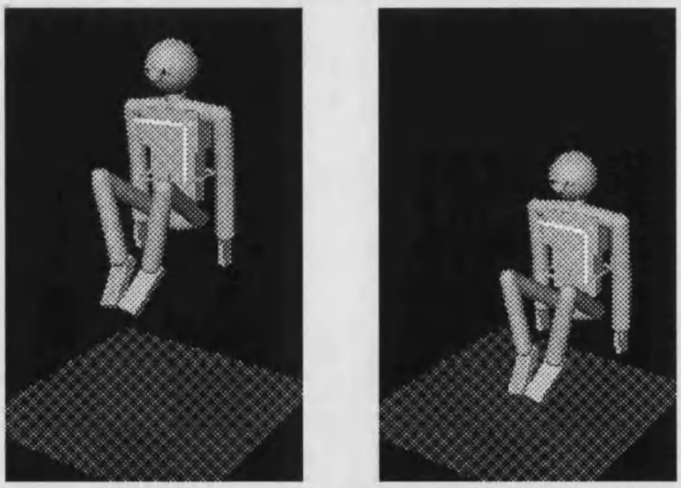


Figure 6.5 Move To Floor Example

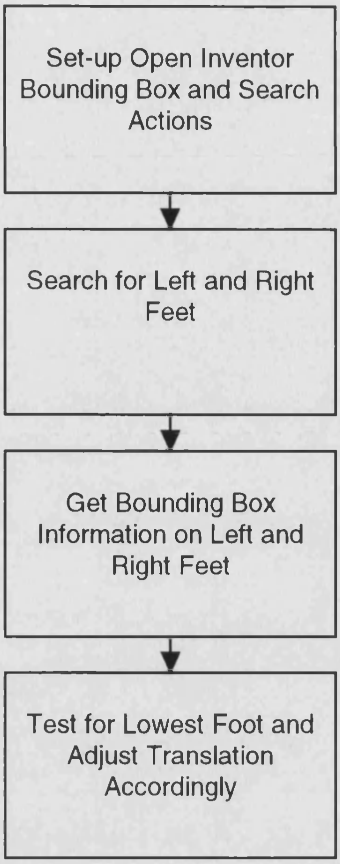


Figure 6.6 Pipeline Process of Move to Floor Function

6.2 High Level Control Function Descriptions

6.2.1 The Global Control Functions

6.2.1.1 Stance Control Functions : Open / Close and Forward / Back

The Stance control functions are perhaps the most general of all high level controls. The controls exist to adjust the stance in terms of openness and direction. The stance of a figure is important in conveying the general feeling or mood of a model. Its elements can describe the more general aspects of an emotional state in terms of positive and negative attributes. The stance controls can operate on the whole figure, including all joint angles at once. This is important as stance is a general posture control which can be expressed in all areas of the body.

Stance is separated into two components, the open / close element and the forward / back element. Each component has a single value which can vary from -1.00 to +1.00 in steps of 0.01. These controls can be adjusted by the animator by using two sliders in the Global Control Panel, see figure 6.7. The positive values represent the more positive aspects of the stance control, opening and forwardness of the stance. The negative values represent correspondingly more negative aspects of the stance control, closing and backwardness of the stance.

The emotional interaction with the Stance controls follows approximately the general interaction rules set out previously in Section 5.3. There is an important difference in use however. As the stance of a figure can convey the positive or negative aspects of mood the link with emotion is more direct with these high level controls than others. The use of a single slider for both open and close, and forwards and back, stance presents the animator with a logical control, but this causes problems with the emotional interaction. The emotional weights which apply to Stance Open will also apply to Stance Close, but as the control function value of Stance Close is negative the emotional weight operate incorrectly. For example consider a joint which may be operated on by the Stance Forward/Back control, the shoulder joint. Let the basic weight w be -0.1, which with a positive control function value, v, will cause an opening of the shoulders. A suitable emotional weight for Joy would be 0.2, thus if the figure were happy then the openness of the stance would be increased. Now consider a negative value of v, this will cause a closing of the shoulders with the same basic weight w. However the emotional interaction of Joy, because it is positive, will increase the basic movement, thus making the posture more closed. This is obviously not correct. To counter this effect all emotional weights are negated for the stance close control. It should be noted that this is not currently done on any other high level control function, so allowances may have to be made, especially with user defined functions.

For Joy and Sadness the emotional interaction with both Stance controls is straight forward due to the nature of the control functions and their relation to positive and negative expression. For Joy the values should be positive and for Sadness the values should be negative. As stance is a general, full body, posturing control the actual values for interaction should not be too large for Joy and Sadness. The back, shoulder and hip emotional weights should be kept to the low or lower-mid ranges. The arm, leg and neck joint emotional weights can be set in the mid range of values to reflect the greater degree of movement in this area with respect to stance.

For Anticipation the interaction should cause a tightening of the stance, a general reduction in effect in most areas. Arm and leg joint angles can be increased however, to reflect the increase in tension. For Surprise the interaction with Stance Open and Close is a general increase all round, increasing the defined movement of the posture control. With Stance Forward and Back the interaction should cause a straightening of the figure, a general reduction, reflecting the increased tension. The emotional interaction values used for Surprise and Anticipation should not be too large as these basic emotions are often mixed with others. Thus the weights will be used as a complement to other emotional interaction. Values should be in the low or lower-mid range.

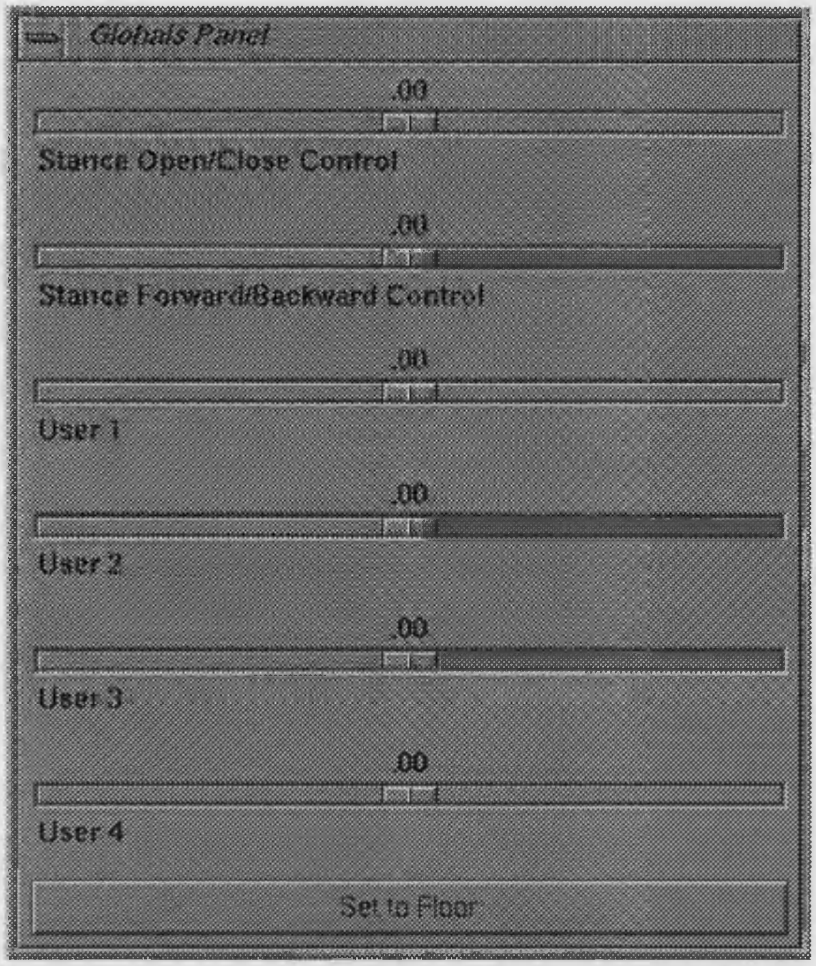


Figure 6.7 Global Control Panel

With the basic emotions of Acceptance and Disgust the interaction follows a similar pattern to that of Joy and Sadness, as one is a very positive emotion and the other more negative. This translates to the majority of emotional interaction weights for Acceptance being positive. Similarly the majority of the emotional interaction weights for Disgust being negative. There are instances, depending on what joints are affected by the stance controls, where opposite weights can be used to enhance the effect. This is largely dependent on the animator and the character they wish to express with the model, thus no strict rules exist. There are some illustrations of this use in the example section which follows. Values of the emotional interaction weights for Acceptance should be kept in the low range for the back, shoulder and hip joint angles. There can be quite dramatic and effective use of mid to high range weights for the arm and leg joint angles.

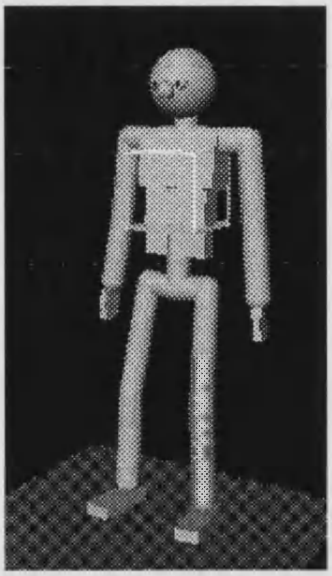
Fear is a largely negative emotion in terms of stance control, so again this factor is prevalent in the definition of emotional interaction weights. The weights for Fear should be mainly negative. Anger is more complex in relation to the stance controls as it depends a great deal on the character of the model. There are many ways of expressing anger in stance, so this is left to the discretion of the animator. A mixture of positive and negative weights by joint group areas works well to steady and affirm the stance of the figure. A general forward movement in the back area also works well as a sign of aggression. The magnitude of the weights for Fear can be in the mid to high ranges as stance is a good area for expression of this basic emotion. The weights for the open and closing of stance should be higher than those of forward and back, to reflect the effect of Fear bringing the body together for protection. The weights for Anger can be of similar degree but in this case the expression of this basic emotion is more apparent in Stance Forward and Back, rather than Open and Close. This represents the forwardness of aggression associated with Anger.

Sample definitions from the test model DEGAS information file are shown in figure 6.8. For Stance Open and Close the effects are based on the back, shoulders and legs. This allows for subtle but effective changes in the figure without changing the values of the main arm joint angles. For Stance Forward and Back the effects are again based in the back but also the main arm joints. This allows them to be outstretched or moved back to enhance the positivity or negativity of the stance.

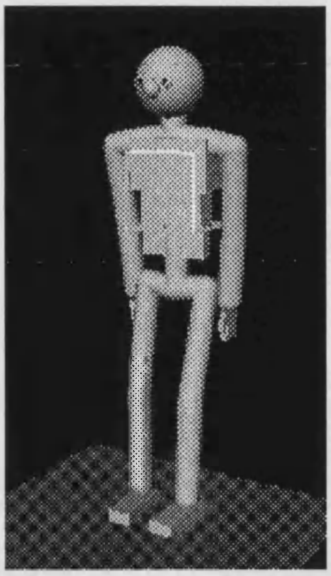
```
#StanceOC
14
2      0.05  0.3   -0.3  0.0   0.3   0.2   -0.4  -0.2  -0.2
5      0.05  0.3   -0.3  -0.2  0.3   0.2   -0.4  -0.2  -0.2
8      0.05  0.3   -0.3  -0.2  0.3   0.2   -0.4  -0.4  -0.2
11     0.05  0.3   -0.3  -0.3  0.3   0.2   -0.6  -0.4  0.3
14     -0.1  0.3   -0.3  -0.3  0.3   0.3   -0.6  -0.6  0.3
17     -0.1  0.3   -0.3  -0.4  0.3   0.3   -0.6  -0.6  0.3
21     -0.1  0.2   -0.2  -0.4  0.5   0.1   -0.4  -0.4  -0.15
22     0.1   0.2   -0.2  -0.4  0.5   0.1   -0.4  -0.4  -0.15
32     -0.1  0.2   -0.2  -0.4  0.5   0.1   -0.4  -0.4  -0.15
33     0.1   0.2   -0.2  -0.4  0.5   0.1   -0.4  -0.4  -0.15
42     0.05  0.4   -0.4  0.3   0.3   0.3   0.4   -0.6  0.3
44     -0.1  0.4   -0.4  0.3   0.3   0.3   0.4   -0.6  0.3
49     0.05  0.4   -0.4  0.3   0.3   0.3   0.4   -0.6  0.3
51     -0.1  0.4   -0.4  0.3   0.3   0.3   0.4   -0.6  0.3

#StanceFB
10
2      -0.1  0.3   -0.3  0.0   -0.4  0.2   -0.3  -0.5  -0.3
5      -0.1  0.3   -0.3  -0.2  -0.3  0.2   -0.3  -0.5  -0.3
8      -0.1  0.3   -0.3  -0.2  -0.2  0.2   -0.3  -0.4  0.4
11     0.1   0.3   -0.3  -0.3  -0.2  0.2   -0.3  -0.4  0.4
14     0.1   0.3   -0.3  -0.3  -0.2  0.4   -0.3  0.2   0.4
17     0.1   0.4   -0.4  -0.4  0.2   -0.2  0.3   0.2   0.3
24     0.15  0.2   -0.2  -0.3  -0.2  0.2   -0.3  -0.2  -0.4
26     0.2   0.2   -0.2  0.3   -0.2  0.4   -0.3  -0.2  0.6
35     0.15  0.2   -0.2  -0.3  -0.2  0.2   -0.3  -0.2  -0.4
37     0.2   0.2   -0.2  0.3   -0.2  0.4   -0.3  -0.2  0.6
```

Figure 6.8 Sample Definitions of Stance Control from the DEGAS Information File

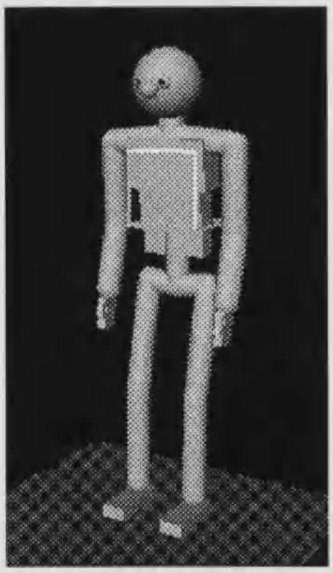
Figure 6.9 shows some examples of stance control applied to a figure. Example A shows Stance Open / Close applied with a value of 0.6, the emotional state is Acceptance. The arms are brought out of the body, the leg stance is widened and the shoulders are opened. Example B has Stance Open / Close applied with a value of -0.3, the emotional state is a mixed emotion of Disgust and Fear. Here the reverse effect is applied, the legs, arms and shoulders are brought in. The disgust and fear bring the arms in toward the body further. Example C shows Stance Forward / Back applied with a value of 0.45, the emotional state is Joy. The forward movement is mainly in the back and arms. Example C is a combination of both stance controls, Open / Close is set to a value of -0.8 and Forward / Back is set to -1.25. The emotional state is a combination of Surprise and Disgust. This shows how the two stance controls can compliment each other.



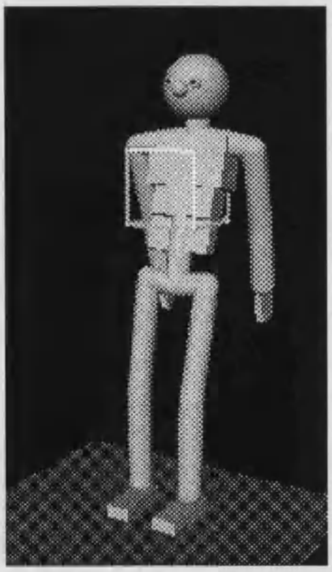
Example A



Example B



Example C



Example D

Figure 6.9 Stance Control Examples

6.2.1.2 User Defined Control Functions

The User Defined high level control functions are global controls which are entirely definable by the animator. They were originally used for the testing of other high level control functions during development, but they have proven to be a useful tool for general use. Through these definable controls an animator can make model specific movements easy to use and manipulate. In this way common movements used for a particular character can be defined and used with ease. Also extra high level functions which are not inherent to DEGAS, but which the animator would find useful are made possible. As the controls are fully definable all joints in the figure may be accessed by these high level functions. This means that, while the usual high level control functions in DEGAS are locally based. the user control functions can be more flexible. For example it could be used to control one arm and one leg, or the hips and back together.

Definition of the User high level control functions follows the standard high level control function interaction. They are defined by controls and emotional interaction on up to 20 joint angles. This restriction means that these controls remain manageable and easy to define. If a greater number of joint angle needs to be controlled then this can be achieved by using more than one User control function. Each User control is defined and controlled by a single value varying between -1.00 and +1.00 in steps of 0.01, see figure 6.7. This should not affect the range of movements possible as the interaction can account for larger joint angle values by using higher weight values.

Emotional interaction through User control functions follows the standard rules set out in Section 5.3 previously. As the function of the User controls are entirely definable, no specific emotional interaction recommendation can be made. It is intended that users either follow the general emotional rules or do not include emotional interaction with these functions. Figure 6.10 shows an example of a user defined control function applied to a figure. The single value of the control function is linked to back, shoulder and arm joints.

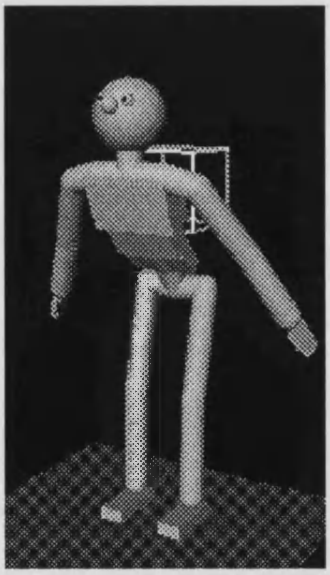


Figure 6.10 Example of User Defined Control Function

6.2.2. Back and Neck Control Functions

6.2.2.1 Lower / Raise Back Control Functions

The Lower and Raise back functions are used to lower and raise the trunk of the model. The range of movements possible within this description is large and so emotional expression through these functions is good. The two control functions could be combined to one simpler function with negative values representing lowering of the back, and positive values representing raising of the back. However the way humans raise their back is not strictly opposite to the way in which it is lowered. To emphasise this difference and allow greater interaction with the controls, lowering and raising are treated separately. This also allows the animator to lower the back to a large degree and then raise it slightly to produce an effect not possible with a single control. The Lower and Raise back control functions affect just the back and head groups. They are represented by two values, controlled by two sliders which vary from 0.00 to 1.00 in steps of 0.01.

The emotional interaction through DEGAS follows the rules set out for general high level control functions, as defined in Section 5.3. The back is a complex and flexible series of joints, so is a good source of emotional expression. The influence of the basic emotions of the emotional state can be defined in a similar way for both control functions, as the general motion of each is related.

For Joy and Sadness the effects on Lower and Raise back are related. For Joy the effect is positive for Raise back and negative for Lower back. For Sadness the effect is negative for Raise back and positive for Lower back. This means that if the figure is joyous then the application of raise back should become more pronounced and the application of lower back should be less pronounced. It should be remembered that the control function being applied is intended. That is, if Lower back is applied then the animator wants to lower the back of the figure. While the lowering of the back can be associated with sadness in some respects, the emotional state of Joy should not negate the lowering of the back. It should produce the effect of lowering the back in a joyous way. This can be achieved through careful emotional weighting varied over the back and neck joints. It is more effective, with respect to Joy and Sadness, to adjust the neck joints more than the lower back joints as expression of these emotions is more pronounced in this area. This is because of the effect of these emotions on muscle tone [45, 48]. The head is a heavy part of the body supported by the neck joints and muscles. If tone is lost or enhanced then the neck will show the effect more than lower back joints. Based on these theories it is recommended that the emotional interaction weights of Joy and Sadness be kept in the low and mid ranges for the back joints, and the high range for the neck joints. The magnitude of the values should increase from the lower back to the higher neck joints.

For Anticipation and Surprise the effects on Lower and Raise back are more complex. The general movement of Anticipation in the back is inward with the increase in tension, the neck moving to complement the back. The movement of Surprise is generally backward and away, with a loss of tension. Both emotions have a similar effect on the lower back, which causes increase backward movement or decreased forward movement. This is to cause the rearward movement in the case of Surprise and allow for inward movement in the case of Anticipation. The back movement should be reduced toward the top joints of the back and the neck joints should re-enforce the back movement. For Anticipation this means a raising of the head expectantly. For Surprise there should be a similar but less pronounced movement. This is best illustrated in the examples section. The interaction values for Anticipation and Surprise should be in the high range for the lower joints in the back, reducing to near zero values in the upper back. The neck joints should be in the opposing high to mid ranges for Anticipation and mid to low ranges for Surprise. It is possible that the neck joints be set higher in magnitude than the normal ranges, with Anticipation to reverse the effect of the Lower and Raise back control functions. This is so the head may be raised a little to complement the closing up of the back.

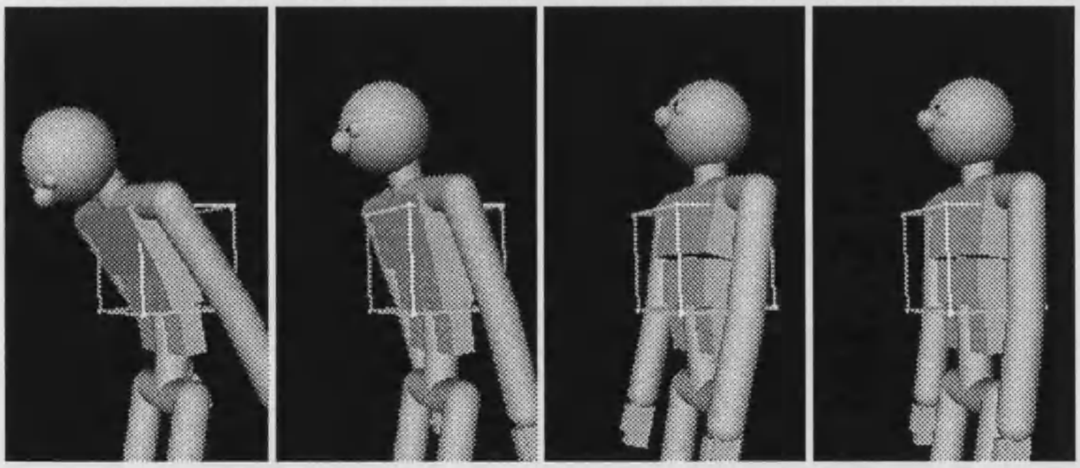
With Acceptance the general movement of high level functions is enhanced. So in this case all joint effects are increased by a small generally uniform amount. Disgust has a similar effect on the lower back, but the reverse effect on the upper and neck joints. This gives an effective twist in the back movement. The upper back and neck are generally more expressive with Disgust, as the reaction is generally to turn the sight or movement away from the source of Disgust. The interaction values for Acceptance should be kept in the low range. Acceptance is a subtle emotion and effects on high level control functions should reflect this. Disgust should cause low to mid range effects on the lower back joints and greater effect on the more expressive upper back and neck joints.

The feeling of Fear should result in the greater closing or curling of the back, especially on the upper back and neck joints. This means an increase in the effects of Lower back and a decrease in the Raise back control function effects. Anger has more subtle effects on the back and neck joints. There is an increase in tension which should cause similar effects to those of Anticipation or Surprise, with less pronounced movement in the lower back. Emotional interaction values for Fear should start in the low range and rise to the high range by the upper neck joint. For Anger values should be kept solely in the low range, or lower-mid range. Causing forward movement in the lower back and corresponding backward movement in the upper back and neck.

Sample definitions from the test model DEGAS information file are shown in figure 6.11. Examples application are shown in figure 6.12. Examples A and B show the basic difference between Sad and Joy. The value of Lower Back in each case is 1.0, but the emotional state in Example A is Sad and in Example B it is Joy. The effect is to lessen the overall effect of the lowered back, but the head and neck are affected more by the change in emotion.

```
#Lower Back
6
2     0.1   -0.3 0.2  1.0  1.0  0.2  0.2  0.2  0.3
5     -0.2  -0.4 0.2  0.6  0.6  0.2  0.2  0.4  0.2
8     -0.15 -0.4 0.4  0.4  0.4  0.2  0.0  0.6  0.0
11    -0.12 -0.4 0.6  0.2  -0.3 0.2  -0.4 0.8  -0.1
14    -0.1  -1.0 0.8  -1.0 -0.2 0.2  -0.6 1.0  -0.2
17    -0.15 -1.4 1.0  -1.4 -0.2 0.2  -1.0 1.0  -0.3

#Raise Back
6
2     -0.1  0.3  -0.2 -1.0 -1.0 -0.2 -0.2 -0.2 -0.3
5     -0.05 0.4  -0.2 -0.6 -0.6 -0.2 -0.2 -0.4 -0.2
8     0.2   0.4  -0.4 -0.4 -0.4 -0.2 -0.0 -0.6 0.0
11    0.3   0.4  -0.6 -0.2 0.3  -0.2 0.4  -0.8 0.1
14    -0.2  1.0  -0.8 1.0  0.2  -0.2 0.6  -1.0 0.2
17    0.2   1.4  -1.0 1.4  0.2  -0.2 1.0  -1.0 0.3
```

Figure 6.11 Sample Definitions of Lower and Raise Back from the DEGAS Information File



Example A Example B Example C Example D

Figure 6.12 Example Application of Lower and Raise Back Control Functions

Examples C and D show a similar effect while Raise Back is applied with a value of 0.5. In Example C the emotional state is Joy, while in Example D this is changed to a complex emotional state of Fear and Anticipation. The effects of this change are subtle, the head is lowered toward a level position and the back is tightened as a consequence of increased tension.

6.2.2.2 Lower / Raise Head Control Functions

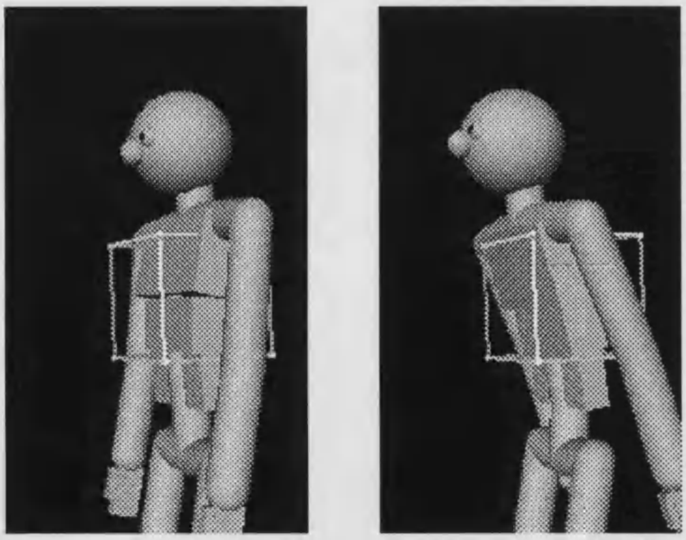
The Lower / Raise Head control functions are similar in use to Lower / Raise Back. The separate high level control is provided as the head will often be used independently from the rest of the back. Again control is provided separately for lowering and raising, though the differences in uses are not so obvious as the lower / raise back control function as the back has more joints.

The area of effect is just the head group of joint angles, currently encompassing the six joint angles in the two neck joints. The control is provided again by two sliders, each varying the values between 0.00 and +1.00 in steps of 0.01.

In terms of emotional interaction much of what has been discussed in the Lower / Raise Back control function applies again to the Lower / Raise Head control function. Special emphasis can be placed by the animator using this separate head control. The same rules for weighting definition which applied to the neck joints of Lower / Raise Back also apply here. Sample definitions from the test model DEGAS information file are shown in figure 6.13. In this case they are exactly the same as those used by the Lower / Raise Back control function, though they need not be.

```
#Lower Head
2
14     -0.1  -1.0  0.8   -1.0  -0.2  0.2   -0.6  1.0   -0.2
17     -0.15 -1.4  1.0   -1.4  -0.2  0.2   -1.0  1.0   -0.4
#Raise Head
2
14     0.2   1.0   -0.8  1.0   0.2   -0.2  0.6   -1.0  0.2
17     0.2   1.4   -1.0  1.4   0.2   -0.2  1.0   -1.0  0.4
```

Figure 6.13 Sample Definitions of Lower and Raise Head from the DEGAS Information File



Example A Example B

Figure 6.14 Sample Definitions of Lower and Raise Head from the DEGAS

Figure 6.14 shows some picture examples of the Lower and Raise head control function applied in conjunction with Lower and Raise Back. Example A shows Lower Head with a value of 1.5 applied to Raise Back with a value of 0.5. The emotional state is set to a complex emotion of Anger and Disgust. The overall effect ensures the head is kept level while the back is raised. Example B shows Raise Head with a value of 1.0 applied to Lower Back with a value of 0.8. The emotional state is the same as Example A, and the overall effect similarly maintains the head level while adjusting the back accordingly.

6.2.2.3 Turn Toward (Whole Body) Control Function

Turn Toward (WB) is a directed high level control function. The emphasis is on turning the main torso and shoulders towards a direction of interest. It can be used well in conjunction with other directed high level control functions such as Point At or Look At.

The control function can affect the back and neck rotation joints and the shoulder joints. This enables the animator to control the torso as one unit to turn the figure in a specified direction. In a similar fashion to other directed control functions it contains just one control value plus the Use flag, which are used in conjunction with the defined position. The value of the control function is restricted to the range -2.00 to +2.00 in steps of 0.01. This produces a range of movement between the initial posture, value 0.00, to the turning of the body completely toward the direction of interest, value +1.00, and beyond. It also allows for negative values for turning away from the specified direction. The control panel is similar in structure to the one shown in figure 6.3.

Through the DEGAS information file the animator can specify which of the back, neck and shoulder joints are affected by the Turn Toward function, and to what degree relative to the others. This function currently overrides all other back and neck joint high level control functions, except the Look At control function. The effects on the shoulder joints are in addition to other control functions. It currently only acts on the flexion and twisting joint angles in the back and neck.

At each update the flexion and twisting joint angles in the neck and back are set to zero. A search is set up and the global position of the head, and its centre is calculated from its bounding box. This is to be used as a reference point. The search applied could be changed to any other node in the figure, the change to the program would be trivial. So for example, the reference point could be set to the upper torso rather than the head. For testing purposes the head has been used. Next the value of the Turn Towards position is obtained from the posture information, and this is adjusted to calculate the position relative to the reference point in global co-ordinates. From this information the relevant angles from the straight forward position are found using basic trigonometry and geometry. For the update to the twisting and flexion joint angles of the back and neck, the calculated angle is weighted by the Turn Toward value and then by the weights defined in the DEGAS information file. These basic weights are adjust according to the emotional state and defined emotional weights, and then normalised so they sum 1.0 after weighting. When these are applied to the back and neck joints this makes the figure turn toward the direction of the Turn Toward position. Finally the shoulder joints defined as affected are adjusted in a similar way to a general high level function, with a weighted turn in the direction according to the Turn Toward value.

For example consider the definition of Turn Toward given in figure 6.16. Let the calculated angles to be applied to the back and shoulders be $\pi/4$ in both twisting and flexion directions. Let the value of the Turn Toward function be 0.8. Thus the base angles to be applied to the back and neck joint angles are $(0.8 * \pi/4)$. The weights for each joint angle are calculated in a similar way to the weights for general high level functions using the formula given in figure 6.15. W is the calculated weight based on the basic weight w, and En and en are the emotional state values and emotional weights respectively.

$$W = w.(1+\sum_{n=1}^{8} e_n E_n)$$

Figure 6.15 Formula for Turn Toward Emotional Weighting

```
#Turn Toward
14
2       0.1    -0.3   0.2    1.0    1.0    0.2    0.2    0.2    0.3
5       0.1    -0.4   0.2    0.6    0.6    0.2    0.2    0.4    0.2
8       0.1    -0.4   0.4    0.4    0.4    0.2    0.0    0.6    0.0
11      0.1    -0.4   0.6    0.2    -0.3   0.2    -0.4   0.8    -0.1
14      0.1    -1.0   0.8    -1.0   -0.2   0.2    -0.6   1.0    -0.2
17      0.1    -1.4   1.0    -1.4   -0.2   0.2    -1.0   1.0    -0.3
3       0.1    -0.3   0.2    1.0    1.0    0.2    0.2    0.2    0.3
6       0.1    -0.4   0.2    0.6    0.6    0.2    0.2    0.4    0.2
9       0.1    -0.4   0.4    0.4    0.4    0.2    0.0    0.6    0.0
12      0.1    -0.4   0.6    0.2    -0.3   0.2    -0.4   0.8    -0.1
15      0.1    -1.0   0.8    -1.0   -0.2   0.2    -0.6   1.0    -0.2
18      0.1    -1.4   1.0    -1.4   -0.2   0.2    -1.0   1.0    -0.3
20      0.1    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
31      0.1    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
```

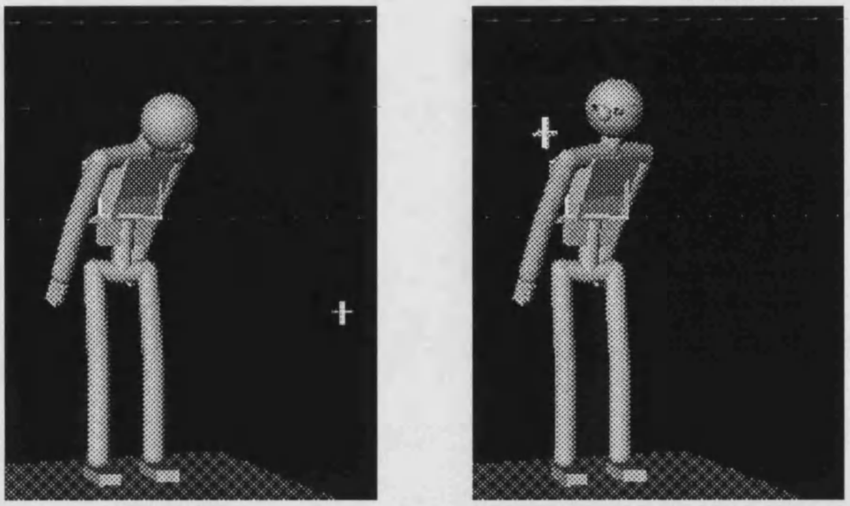
Figure 6.16 Sample Definition of Turn Toward from the DEGAS Information File

These calculated weights are then normalised by the two groups, neck and back flexion angles affected and neck and back twisting angles affected. Thus the sum of the weights W for the back and neck flexion joint angles equals 1.0 and similarly for the twisting joint angles. These weights are multiplied by the base angles to give the angle to be applied at that particular joint angle. Finally the standard formula for general high level control functions is used for the shoulder joint angles affected to move them in a direction complementary to the overall movement.

This method is not a precise movement method and there are problems which occur when the direction is behind the figure. It does however provide a useful tool in many situations. It should be remembered that movement of a real human is also not precise. The emotional interaction applied for this control function can follow similar rules to that of the

Lower and Raise Back high level controls. The difference is that some adjustment may be needed in order to complement the directed nature of this function.

Example A from Figure 6.17 shows Turn Toward applied to a model. The direction of interest is defined by the point dragger to the right of the figure. Example B is a demonstration of the use of the Look At control function in conjunction with Turn Toward and is discussed in the next section.



Example A Example B

Figure 6.17 Examples of Turn Toward and Look At in Use

6.2.2.4 Look At Control Function

Look At is a directed high level control function used to control the neck and turn the head to face a specified direction. It is useful when used in conjunction with another directed control functions, or on its own to direct the gaze of the head. The control is restricted to the neck joint angles, so only the head and neck are affected by this function. If more body control is needed then other directed functions, such as Turn Toward (WB), can be used effectively with this control function.

This function has only one variable control value, excluding the Use flag and defined position, which determines the degree to which the movement is carried out. This can vary from -2.00 to +2.00 in steps of 0.01. This range of values allows the animator to control the direction of the head between the start position, value 0.00, to the end position, value 1.00, where the head is looking straight toward the goal and also beyond. It also allows the use of negative values to look away from the direction specified. The Use flag simply determines whether the function is used or not. The control panel is shown previously in figure 6.3.

In execution it is handled in a similar fashion to the Turn Toward high level control function. The main difference being that it operates only on the neck joints and cannot affect the shoulders. It can be used in conjunction with the Turn Toward control function however. It only initialises the neck joints after Turn Toward has been applied, and then works in the same manor. In this case however, the position value is adjusted not just by the global position of the head, but also by the global orientation of the head. This is done by calculating the position value in terms of the co-ordinate system based at the initial neck joint. Inventor provides useful techniques for calculating these values. The transformation matrix can be calculated for the sphere at the base of the neck, and its inverse is used to translate the position value of the function to the required co-ordinate system.

The definition follows the same rules as the Turn Toward control function, as does the interpretation of emotional weights. A sample definition from the DEGAS information file is shown in figure 6.18. The emotional interaction can also be defined in the same way, and by the same rules, as Turn Toward.

```
#Look At
4
14    0.1   -1.0  0.8   -1.0  -0.2  0.2   -0.6  1.0   -0.2
17    0.1   -1.4  1.0   -1.4  -0.2  0.2   -1.0  1.0   -0.3
15    0.1   -1.0  0.8   -1.0  -0.2  0.2   -0.6  1.0   -0.2
18    0.1   -1.4  1.0   -1.4  -0.2  0.2   -1.0  1.0   -0.3
```

Figure 6.18 Sample Definition of Look At from the DEGAS Information File

Figure 6.17 shows Look At in use when combined with Turn Toward in Example B. The value and direction of Turn Toward is the same as Example A. The Look At control function is applied afterwards and the direction is shown by the point dragger to the left of the picture. Note that the back joints remain the same in both examples.

6.2.3 Arms and Shoulder Control Functions

6.2.3.1 Shrug / Negative Shrug Control Functions

The Shrug and Negative Shrug high level control functions can manipulate the shoulders and arms to produce raising or lowering of the shoulders. In a similar way to the raising and lowering of the back two controls are specified, Shrug and Negative Shrug. These are separate to allow for the distinct differences between raising and lowering of shoulders. It also allows for the mixing of the two movements, which are not strictly exclusive.

The area of effect of the Shrug and Negative Shrug functions are the shoulder and arm joint groups. When adjusting the shoulders the arms, which are a connected component of the figure, are also moved accordingly. To allow correction to any resulting movement, and also more expressive movement, arm groups are included in the control. Each of the functions is controlled by a single value, in the range 0.00 to 1.00 in steps of 0.01, by means of a slider.

Emotional interaction for Shrug and Negative Shrug is defined in the standard way for general high level control functions. While the Shrug control function can be varied in its application, and hence emotional interaction, Negative Shrug has important emotional connections. As its name suggests, it is particularly affected by negative basic emotions.

For Joy the effect on shoulder joint angles for Shrug is to increase movement slightly, in the low or lower mid ranges. If the arm joints are affected then the movement should be openness to reflect the positive connotations of Joy. The values for the arm joints should be fitting to the basic weight of arm movement. For Sadness the overall movement of Shrug should be decreased, reflecting the loss of muscle tone associated with this basic emotion. Negative mid- to high-range weighting values should be used as Shrug is a motion controlling the weight of the arms and as such should show a large degree of change.

For Negative Shrug the effects of Joy and Sadness reflect the positivity and negativity associated with the emotions. Thus weighting should be negative for Joy and positive for Sadness to decrease and increase movement respectively. Again the weights can be in the mid- or high-ranges reflecting the greater movement because of the weight of the arms.

Anticipation for both Shrug and Negative Shrug should bring joints inwards as a consequence of increased muscle tone. If arm joints are used the arm should be brought closer to the body and elbow joint angles increased. For Surprise the effect should be similar with the increase in tension, but arms should be moved back and outward. The weighting values are subtle and should be in the low or lower mid-ranges, below half-way.

Acceptance with the Shrug and Negative Shrug control functions should reflect openness. The arms joints especially should be opened up and hands turned outward. The effect on shoulder joints should be reduced. Disgust should have the opposite effect, bringing arms backward and toward the body, shoulder movement should also be increased. For both basic emotions the weighting values should be in the low range for shoulder joint angles, but larger values can be used for arm joints to counter the basic weight movement if necessary.

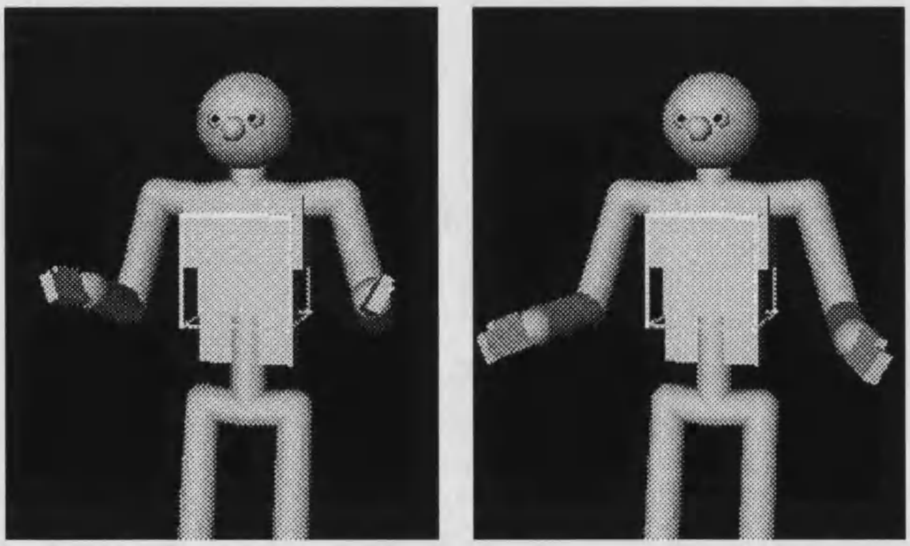
The emotional interaction of Fear on Shrug and Negative Shrug should increase shoulder movement, reflecting increased tension, and bring arm movement in toward the main torso of the figure. The magnitude of the weights should be set to mid or high ranges to reflect the difference in movement necessary to express this emotion. The effect of Anger should be as a result of increased tension, thus a tightening of shoulder movement can be very effective. The resulting effects of the shoulder joint interaction down the connected arm joints can be enough to mean no further interaction is needed, as in the example following. Though forward movement of the arms can reflect aggression is needed.

Sample definitions of Shrug and Negative Shrug from the DEGAS information file are shown in figure 6.19. In this case the Shrug control function also affects the arms to bring them up in a Gallic manner.

Figure 6.20 shows four examples of Shrug and Negative Shrug in use. Examples A and B show Shrug applied with a value of 0.5. The emotional state in A is Anticipation and in B it is Acceptance. The difference can be seen most in a retraction of the muscles causing tighter shoulders and elbow joints in Example A. In Example B the expression is much more open and accepting. Examples C and D show Negative Shrug applied with a value of 0.45. The emotional state is Anger in Example C and a complex emotion of Sadness and Anticipation in Example D. In these examples the limits on the shoulder joints have been increased slightly to allow for exaggerated expression. The differences between the two examples can be seen by the extended lowering of the shoulders associated with the sadness, and the inward movement of the arms associated with the anticipation.

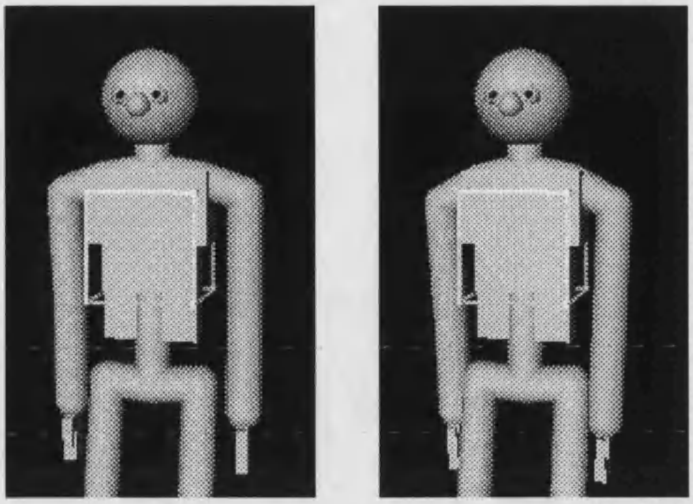
```
#Shrug
16
20    -0.05 0.2   -0.4  0.2   0.1   -0.2  0.2   0.4   0.6
22    0.25  0.2   -0.4  0.2   0.1   -0.2  0.2   0.4   0.6
23    0.1   0.2   -0.4  -0.8  0.4   0.2   -0.2  -1.3  0.0
24    0.15  0.2   -0.4  -0.8  -0.4  0.3   -1.5  -0.3  0.0
25    -0.15 0.2   -0.4  -0.2  0.2   0.3   -0.3  -0.3  0.0
26    1.5   -0.3  -0.4  0.3   0.2   -0.4  0.4   -0.6  0.0
27    -1.0  -0.3  -0.4  -0.3  0.0   0.2   -0.2  -0.6  0.0
29    -0.25 -0.1  -0.4  -0.3  0.0   0.3   -0.3  -0.3  0.0
31    -0.05 0.2   -0.4  0.2   0.1   -0.2  0.2   0.4   0.6
33    0.25  0.2   -0.4  0.2   0.1   -0.2  0.2   0.4   0.6
34    0.1   0.2   -0.4  -0.8  0.4   0.2   -0.2  -1.3  0.0
35    0.15  0.2   -0.4  -0.8  -0.4  0.3   -1.5  -0.3  0.0
36    -0.15 0.2   -0.4  -0.2  0.2   0.3   -0.3  -0.3  0.0
37    1.5   -0.3  -0.4  0.3   0.2   -0.4  0.4   -0.6  0.0
38    -1.0  -0.3  -0.4  -0.3  0.0   0.2   -0.2  -0.6  0.0
40    -0.25 -0.1  -0.4  -0.3  0.0   0.3   -0.3  -0.3  0.0
#Negative Shrug
6
20    -0.1  -0.4  0.4   0.0   0.0   0.0   0.4   0.3   -0.3
22    -0.2  -0.4  0.4   -0.2  -1.0  -0.5  0.3   0.2   -0.2
23    0.3   -0.4  0.4   -0.5  -0.5  -0.3  0.4   0.3   -0.3
31    -0.1  -0.4  0.4   0.0   0.0   0.0   0.4   0.3   -0.3
33    -0.2  -0.4  0.4   -0.2  -1.0  -0.5  0.3   0.2   -0.2
34    0.3   -0.4  0.4   -0.5  -0.5  -0.3  0.4   0.3   -0.3
```

Figure 6.19 Sample Definition of Shrug and Negative Shrug from the DEGAS Information File



Example A Example B

Figure 6.20 Examples of Shrug and Negative Shrug in Use



Example C Example D

Figure 6.20 Examples of Shrug and Negative Shrug in Use

6.2.3.2 Join Arms Control Functions

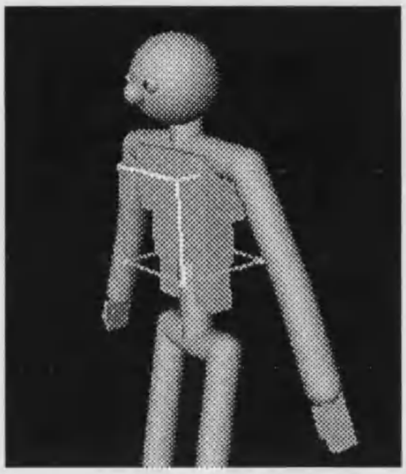
The Join Arms control function is a general posturing tool used to bring the arms towards or away from each other. While it is primarily an arm-based movement there exists the possibility to include the shoulders in the motion. This means it can be used as a posturing tool to further open or close the stance in addition to the less area-specific Open / Close Stance control function.

The joints affected by the control function are all of the arm joints and the shoulder joints. This allows a large degree of freedom for the animator to define how the arms are bought together. The function has a single value ranging from -1.00 to +1.00 in steps of 0.01. This means the same function is used to move the arms away from each other as to join them. The latter is achieved by setting a negative value. Due to the usual exclusiveness of joining and parting the arms, it was thought unnecessary to have two separate functions as in the lowering and raising back control functions.

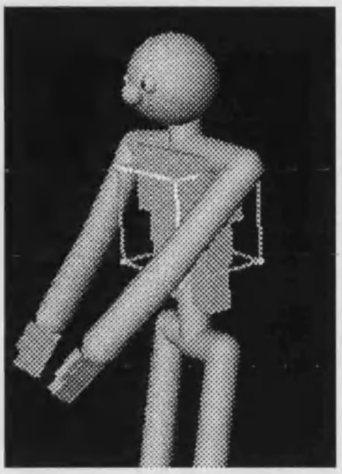
Emotional interaction depends on the level of complexity of the arm joining movement. In the example case defined in figure 6.21 just the top arm joints are defined as affected, thus emotional interaction is limited. This definition does provide a more flexible function as it can be applied in most situations, regardless of the current position of the arms. If the figure were sat down more complex definition may be required. Emotional interaction follows the general rules with a particular emphasis on the effects of tension and muscle tone, which have more obvious effect on the arms. Figure 6.22 shows simple examples of Join Arms in practice. Example A has a Join Arm value of -0.4, Example B has the value 0.3.

```
#Join Arms
2
23    -0.5  0.0   0.0   0.5   -0.5  0.2   0.0   -0.2  0.0
34    -0.5  0.0   0.0   0.5   -0.5  0.2   0.0   -0.2  0.0
```

Figure 6.21 Sample Definition of Join Arms from the DEGAS Information File



Example A



Example B

Figure 6.22 Example Use of Join Arms Control Function

6.2.3.3 Point At Control Functions : Left Arm, Right Arm and Both Arms

The Point At control functions have not been fully implemented in the DEGAS posturing system. Though research has been done in testing techniques which could be used for suitability and emotional interaction. These are based on techniques similar to those used by the Turn Toward and Look At control functions. An example of the testing can be seen in figure 6.23. The method uses quarternion rotations instead of Euler angles to represent the arm and elbow joints, the main problem lies in converting these to usable Euler angles.

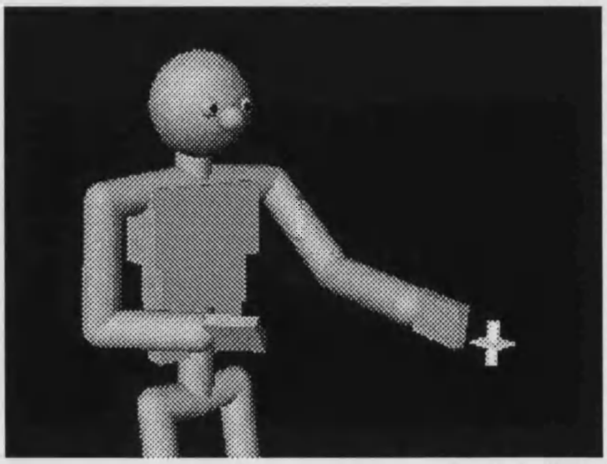


Figure 6.23 Examples of Point At Arm Testing

6.2.4 Leg and Hip Control Functions

6.2.4.1 Join Legs Control Function

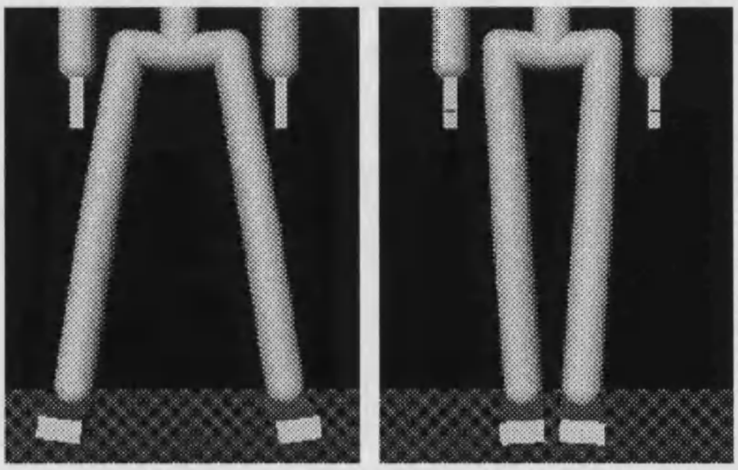
The Join Legs control function is similar in use to the corresponding arms function. It is a general movement for closing or opening of the legs. It can be used to further open or close the stance of the figure in a more area specific way. It can also be tailored to suit the uses of the model it applies to. For example a figure could use a separate DEGAS file for when the character is sitting rather than standing. By defining this function appropriately, the changes in how a figure should be updated can be handled in a sensible way.

The affect of the control function is restricted to the leg and hip joints. This allows leg adjustment, and any corresponding adjustments in the hips to be made. The control function is defined by a single value ranging from -1.00 to +1.00 in steps of 0.01. The negative values correspond to moving the legs apart, or opening of the stance. As with the Join Arms function, it was not thought necessary to have two separate functions for joining and opening of the legs.

Emotional interaction is restricted by complexity of implementation, as with the join arms control function. With the close connection with stance control the same rules can apply to this control function. Allowances have to be made if the function is tailored to a particular situation, such as sitting. The sample definition given in figure 6.24 follows the Join Arms example where only the top joints of the leg are used. Again this allows for flexibility of use.

```
#Join Legs
2
42    -0.5  -0.4  0.4   -0.3  -0.3  -0.3  -0.4  0.6   -0.3
49    -0.5  -0.4  0.4   -0.3  -0.3  -0.3  -0.4  0.6   -0.3
```

Figure 6.24 Sample Definition of Join Legs from the DEGAS Information File



Example A Example B

Figure 6.25 Example Use of the Join Legs Control Function

Figure 6.25 shows two examples of use of the Join Legs control function. In Example A the value is -0.7, in Example B it is 0.15. In both cases the move to floor function was applied to the figure after adjustment to maintain the connection to the floor.

6.2.4.2 Lean Legs Control Function

The Lean Legs control function is a posturing tool to lean the figure forwards or backwards using primarily the leg joints. It can be used as a further area specific refinement of the Stance Forward / Backward control function. The nature of the movement means that the translation of the figure may also be affected to maintain feet positions in relation to the floor.

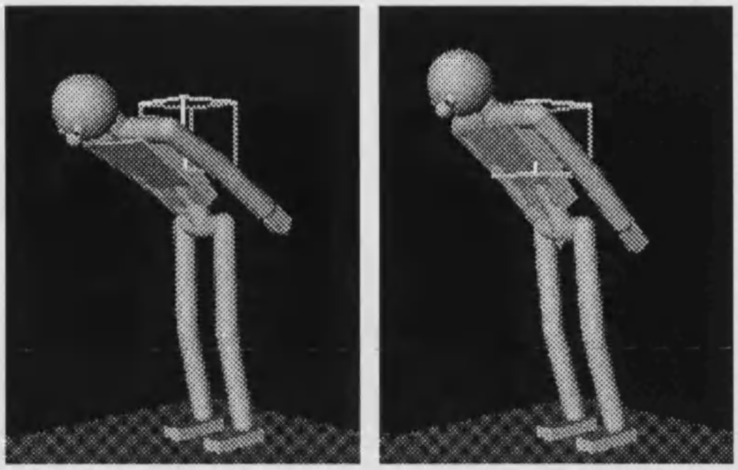
The primary area of effect is the leg joint angles, though limited control over the back joints is also possible. The limitation is imposed by a maximum number of joints which it is able to affect, set at 20. The limits are to restrict movements to their intended areas, so that they do not become too general. As mentioned, the movement may also automatically adjust the translation of the figure to maintain foot positioning. The control function is defined by a single value ranging from -1.00 to +1.00 in steps of 0.01. This allows forward and backward leans by using positive and negative values respectively.

As the Lean legs value is applied throughout the figure the function also affects the global rotation so as to keep the feet level on the ground. This technique overrides previous low level effects on the ankle joints, but the Tip Toes function can still be applied. A sample definition is given in figure 6.26. The emotional interaction can be taken based upon the same principles as Forward / Back Stance control and leaning of the back.

```
#Lean Legs
5
2      -1.0  -0.4  0.4   0.4   -0.4  0.2   -0.2  0.3   0.0
5      -1.0  -0.4  0.4   0.2   -0.4  0.2   -0.2  0.4   -0.4
8      -1.0  -0.4  0.4   -0.2  -0.4  0.2   -0.2  0.5   -0.5
46     -1.0  -0.2  0.2   -0.3  -0.4  0.2   -0.2  -0.6  -0.6
53     -1.0  -0.2  0.2   -0.3  -0.4  0.2   -0.2  -0.6  -0.6
```

Figure 6.26 Sample Definition of Lean Legs from the DEGAS Information File

Examples of Lean Legs in use are shown in figure 6.27. In each example the value of Lean Legs is kept constant at 0.2, only the emotional states are changed. In Example A the emotional state is a complex combination of Anticipation and Fear. This causes a tightening of the leg and back joints used and hence the lean is exaggerated slightly. In Example B the emotional state is Surprise, which causes a general movement back and away from the lean direction.



Example A Example B

Figure 6.27 Example Use of the Lean Legs Control Function

6.2.4.3 Raise Legs Control Functions : Left Leg and Right Leg

The Raise Leg control functions are used to lift the legs in a defined manner. This can be tailored to suit the situation, for example walking, running or climbing stairs. The functions are separated to provide control over the legs individually.

The functions each affect the appropriate leg joints, either left or right, and also the complete hip joints. This allows the left leg to be raised with appropriate adjustment to the left and right hip joints. The function values range from 0.00 to +1.00 in steps of 0.01, which allow only for lifting of the legs.

The emotional interaction of the Raise Leg control functions is based on the positivity or negativity of the emotions. The interaction is again based on the general model detailed in Section 5.3. Basic emotions which are clearly positive or negative have a larger effect on the way a leg may be lifted. The other emotions such as Anticipation, Surprise and Anger have slight or no effect in this area, though the animator can define more interaction if need.

For Joy and Sadness the emotional weighting should reflect positivity and negativity respectively. With the Raise Leg control functions this depends on how the base weights w, are defined. For Joy the lifting of the leg at the hips and upper leg should be increased, as well as the bend in the knee. The angle of the ankle should be decreased to raise the foot higher if affected by the control function. The opposite applies to Sadness. This reflects the lose of muscle tone, and weights should be higher in magnitude where the definition of the control function has large base weights. The overall effect should be to lower the foot as though it had become heavier. The magnitude of the emotional weights for Joy and Sadness should complement the base weights w, of the Raise Leg control function. If the base weights are high then the reduction caused by Sadness should be higher. The additions caused by Joy should be kept to the low and lower-mid ranges, as the effect can be too dramatic if larger weights are used.

Anticipation emotional interaction is as a result of increased muscle tension, causing a tightening of the joints and a general increase in the joint angles. Again Anticipation effects should be subtle so the magnitude of the weights should be kept small in the low range. For Surprise the interaction will mainly be a reduction in the main leg joint. This has the effect of bringing the entire leg back and little further interaction is necessary. This is because the leg will be mainly supported by the upper leg muscles, so the rapid change in tension as the result of a surprise will affect this joint the most. Values for this weight should be in the mid range or upper range to suit the character and implementation of the Raise Leg control function.

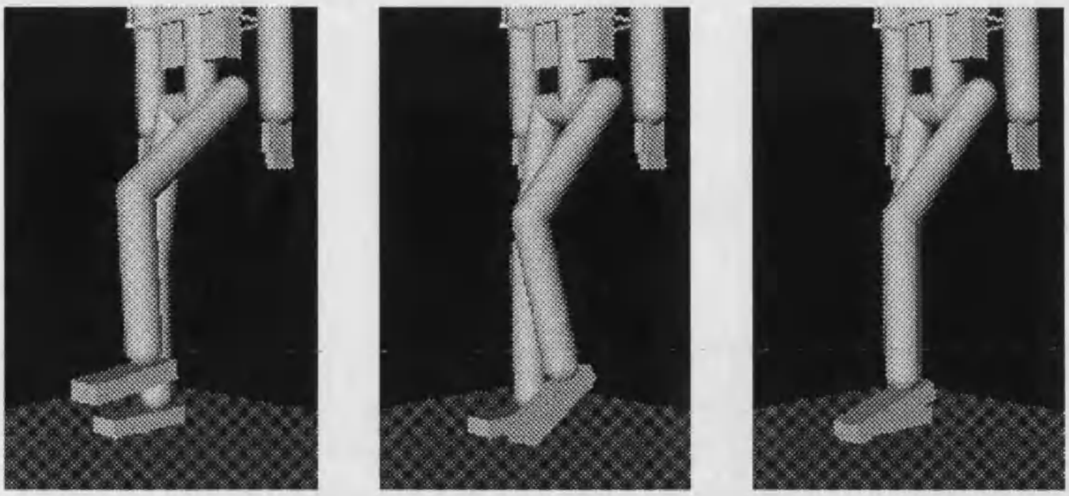
As with Joy and Sadness the overriding effects of Acceptance and Disgust are as a result of the positivity or negativity of the basic emotions. Acceptance is similar in implementation to Joy, with the adjustment that the direction of the leg is becoming more forward and pointed rather than just higher. Disgust should cause a reduction in the upper leg joints to bring the leg down further with a large increase in lower joints to bring the foot back. Emotional weighting values for Acceptance and Disgust should be in the low or mid ranges except where, to achieve the desired effect, overriding of the basic weights is needed. In these situations emotional weights can be in the upper range or greater.

The emotional interaction of Fear and Anger in the Raise Leg control function should be minimal unless the character definition requires it. A mild effect can be applied to mainly the lower leg joint angles of the knee and ankle to reflect an increase in muscle tone as a result of the emotions. The emotional weighting values should be kept to the low range.

Sample definitions from the test model DEGAS information file are shown in figure 6.28. The values are only given for one leg as the definition of the other leg is generally the same, though it need not be. Of note are the minimal values for Surprise, Fear and Anger. The effects of these basic emotions are implemented mainly in the top joint of the leg, or subtly in the closing or tightening of the leg. This means that the basic shape of the leg is maintained.

```
#Raise Leg Left
5
41    0.2   0.3   -0.3  0.1   0.0   0.1   -0.1  0.0   0.0
42    -0.2  0.2   -0.2  0.1   0.0   0.2   -0.3  0.0   0.0
43    1.0   0.2   -0.2  0.1   -0.2  0.2   -0.2  -0.2  0.1
45    1.0   0.2   -0.2  0.3   0.0   0.3   0.3   0.2   0.1
46    0.4   -0.2  0.2   -0.2  0.0   -1.0  0.3   0.0   -0.1
```

Figure 6.28 Sample Definitions of Raise Leg from the DEGAS Information File



Example A Example B Example C

Figure 6.29 Examples of Use of the Raise Leg Control Function

Examples of use of the Raise Leg control function are shown in figure 6.29. In each example the value of the Raise Leg is set at 0.3, only the emotional state values are changed. Example A has an emotional state of Acceptance. This is reflected in the positivity with which the leg is raise, particularly in the ankle and knee joints. Example B has an emotional state of Disgust. The negativity of the emotion causes a retraction of the leg through the upper leg and knee joints. This is complemented by an increase in the ankle joint further bring the foot away from the forward direction. Example C has an emotional state of Sadness. The emotion is again negative, thus a reduction in the upper leg and knee joints from loss of muscle tone. In contrast to Example B the negativity is expressed differently as there is no implied direction to the emotion.

6.2.4.4 Raise Feet Control Functions : Left Leg and Right Leg

The Raise Feet control functions are provided as a way to lift the feet more directly than the Raise Leg control functions. The emphasis is on foot-directed movement rather than leg control. So, for example, this control function could be set up to just operate on the ankle and raise the toes rather than the whole foot.

The area affected is just the appropriate left or right leg group, no control over the hips, as in Raise Leg, is provided. This is intended to re-emphasise the idea of foot rather than leg movement. The motion is controlled by a single value for each foot ranging from 0.00 to +1.00 in steps of 0.01, which restricts the movement to just positive raising values.

The emotional interaction through the DEGAS information file is similar to that of the Raise Leg control function, and follows the general interaction for high level control functions set out in section 5.3. The rules which applied to the Raise Leg function also apply in a similar way here. If the leg is used then the effects of the basic emotions on the leg joint angles are the same. The only substantial difference is in how the foot, specifically the ankle joint, is operated on. With Raise Foot care must be take to ensure the general movement which results from emotional interaction fits with the rules detailed for the Raise Leg function. For example making the direction of the foot more positive depends on the basic weight for the ankle joint.

The example DEGAS information in figure 6.30 demonstrates the case of using the Raise Foot control function to simply raise the toes of the figure. As such it only operates on the ankle joints. The large emotional weighting value corresponding to acceptance is to counter the direction of movement defined by the basic weight.

```
#Raise Foot Left
1
46    -0.5  0.2   -0.2  0.1   0.3   -1.0  -0.1  0.1   -0.1
```

Figure 6.30 Sample Definitions of Raise Foot from the DEGAS Information File

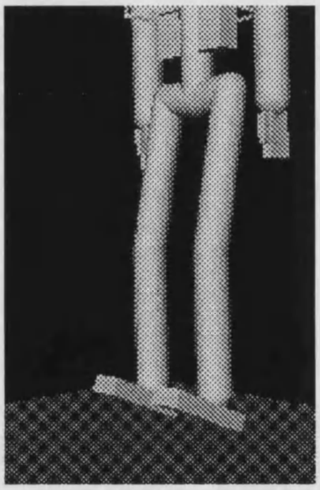


Figure 6.31 Example of Use of the Raise Foot Control Function

Figure 6.31 shows the Raise Foot function in use, applied to each foot with a value of 0.5. After application the Move-to-Floor function has been applied to maintain the figure position relative the floor. Lowering of the foot could be applied by weight negation in the Raise Foot definition, or through use of the Tip Toe control function.

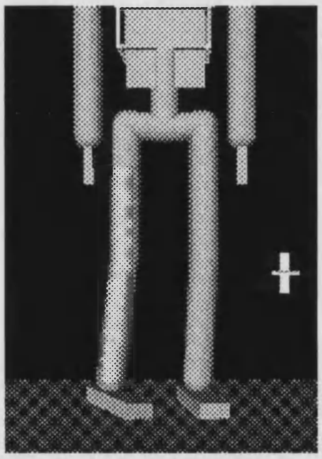
6.2.4.5 Leg Point Control Function

The Leg Point control function is a goal directed function, which is more subtle in use than the other directed functions. For the Turn Toward (WB) and Look At control functions the movement is very noticeable and goal directed. With Leg Point the movement is generally minor and not usually directly towards the area of interest. It represents a commonly used method of body language used to show general emotional elements of positivity, negativity or neutrality. Often when using this sort of body language the person is not aware of their actions, it is largely subconscious. The movement can be made less subtle when using a seated figure as the degree of movement is greater.

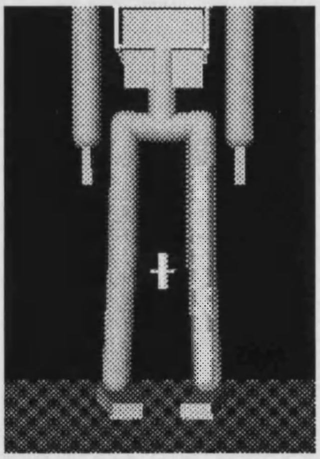
The area affected by the Leg Point control function is restricted to the leg and hip joints. The control is similar in structure to the previous directed control functions. It uses the Point Dragger to define the direction, with a toggle switch to indicate use and a single value. The value is restricted to the range -1.00 to +1.00 in steps of 0.01, see the previous figure 6.3. This allows for pointing toward and away from the area of interest through the use of positive and negative values.

```
#Point At Legs
2
44    1.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
51    1.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
```

Figure 6.32 Sample Definitions of Point At Legs from the DEGAS Information File



Example A



Example B

Figure 6.33 Example of Use of the Point At Leg Control Function

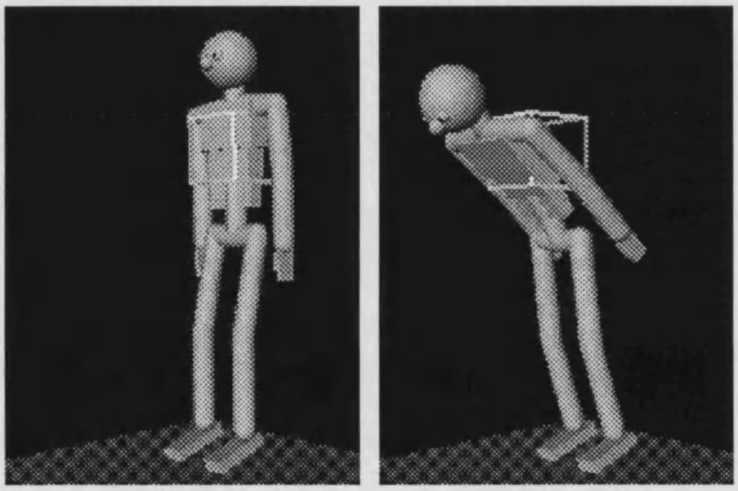
The main movement of turning is applied to the top joint of the leg using similar techniques to those of Turn Toward and Look At. Secondary movement applied to other leg joints and Hip joints is applied in a similar way to shoulder joint use with Turn Toward, through normal weighting functions. A sample definition is shown in figure 6.32 and examples of use are shown in figure 6.33. Emotional interaction is not used in the turning of the leg, though it can be applied in the usual way to secondary movement. The examples demonstrate the application of direction to the legs. With a central position of the point dragger, illustrated in Example B, the control function can be used to turn the legs inward.

6.2.4.6 Tip Toes Control Function

The Tip Toes control function is used to position the model up on its toes. The translation of the figure is adjusted so the control function can be used to increase the height of the character. The movement affects the entire legs group so more complex movements than simple foot adjustment can be achieved. The nature of the movement may also result in automatic global translation adjustment to maintain the position of the model relative to the floor. This uses the Move-to-Floor control function. The Tip Toes control function is defined by a single value ranging from -1.00 to +1.00 in steps of 0.01. The positive values represent the lifting up of the model on its toes. The negative values should move the character back on its heels. Figure 6.34 shows a simple sample definition of the control function from the DEGAS information file. Emotional interaction is limited by the intended effect of the control.

```
#Tip Toes
2
46    0.5   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
53    0.5   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
```

Figure 6.34 Sample Definitions of Tip Toes from the DEGAS Information File



Example A Example B

Figure 6.33 Examples of Use of the Tip Toes Control Function

Figure 6.33 shows some examples of use of the Tip Toes control function. Example A is a simple illustration of the result of applying the control function, demonstrating the height increase as a consequence of the automatic application of Move-to-Floor. Example B shows the use of Tip Toes applied in conjunction with the Lean Legs control function. This illustrates how Tip Toes can be used effectively to enhance other high level controls.

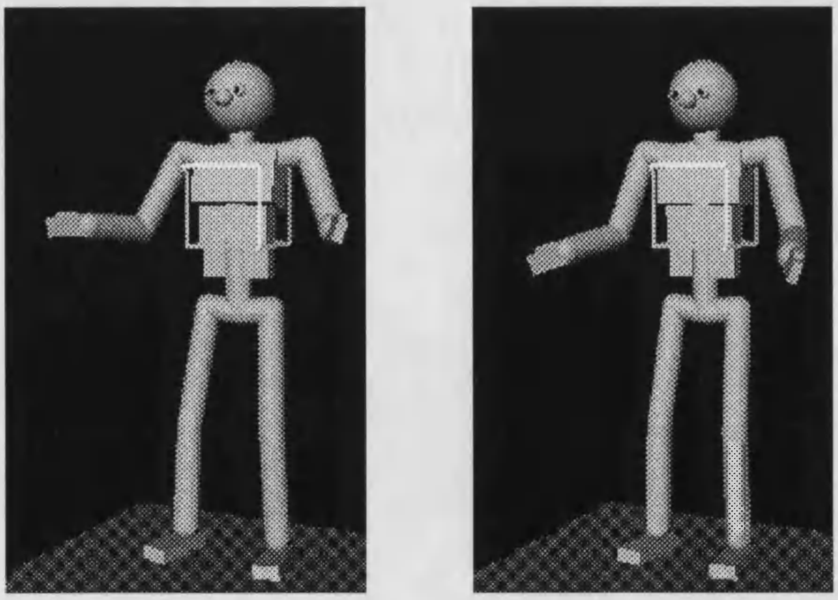
6.3 Examples

6.3.1 Introduction

This section shows some examples of combined high level function controls applied to a human figure model. In each case the figure is postured using high level control functions with limited use of low level controls. The results of altering the emotional state of the figure are illustrated by showing each example with two or three different emotional states while maintaining the same posture values.

6.3.2 Combined High Level Control Examples

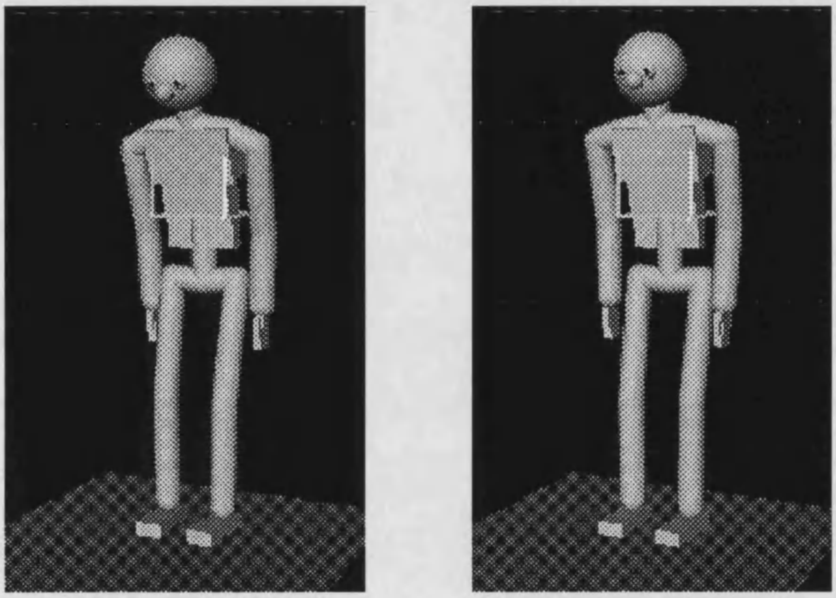
The first example is shown in figure 6.34. The high level control functions used are Open / Close Stance (0.7), Forward / Back Stance (0.4), Raise Back (0.3) and Shrug (0.4). In Example A the emotional state is Joy (0.6), for Example B this is changed to Sad (0.6). The high level elements of open and forward stance, raise back and shrug are still maintained, but the way they are carried out is altered. The sadness causes the arms to drop lower, with similar movement in the shoulder joints. The back joints are also raised to a lesser degree. General stance is less open and limbs are closer to the body. While the difference in emotional state is quite large, the difference in posturing is subtle because of the general positive nature of the overall stance.



Example A Example B

Figure 6.34 Combined Example (i)

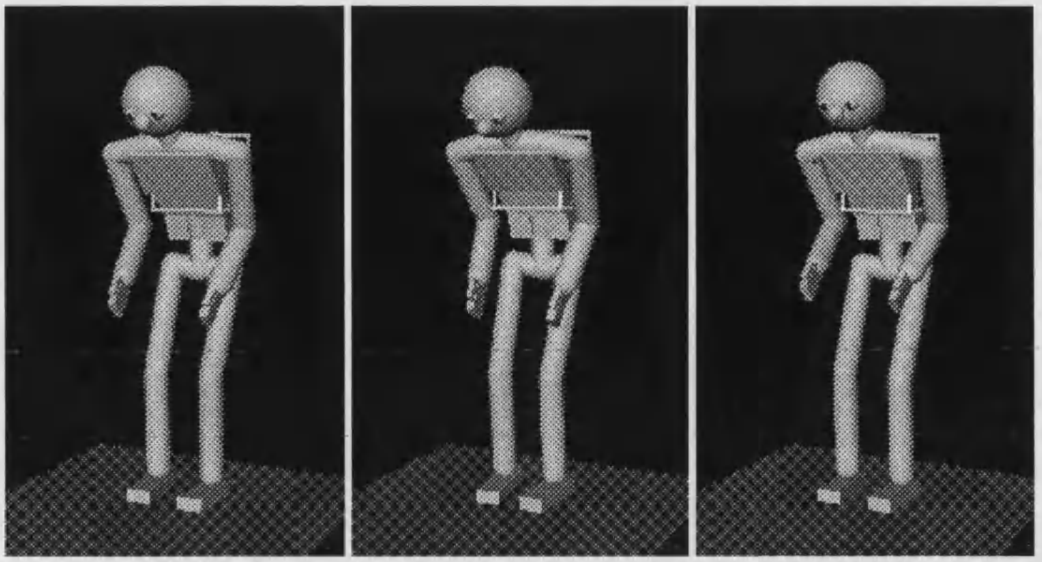
Combined example (ii) is shown in figure 6.35. Here the overall stance is a negative one with some positive elements. The high level control functions used are Open / Close Stance (-0.2), Lower Back (0.4), Negative Shrug (0.3) and Forward / Back Stance (0.4). The emotional state in Example A is Sad (0.6), and in Example B it is Joy (0.6). The sadness in Example A is shown through dropped shoulders, the closeness of the arms and legs, and the dropped back joints. In Example B the Joy reduces these elements by raising the shoulders and lessening the extent of the closeness of arms and legs. The back is an area of particular interest as the reduction in lowering is apparent more in the neck joints than the lower back.



Example A Example B

Figure 6.35 Combined Example (ii)

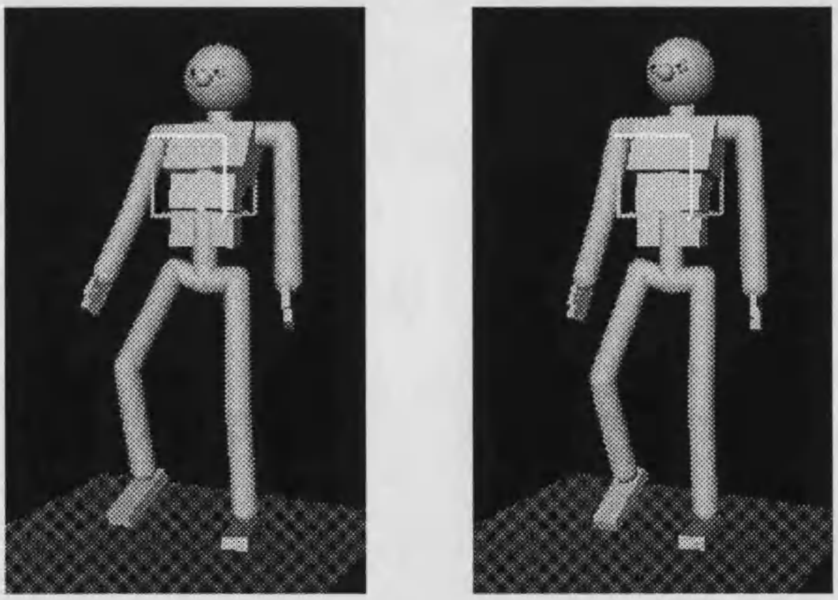
Combined example (iii) is a more complex demonstration of high level posturing, figure 6.36. The high level control functions used are Lower Back (0.8), Raise Leg Left (0.1), Raise Leg Right (0.1), Tip Toes (-0.1), Open / Close Stance (-0.35) and Forward / Back Stance (1.4). There is also some slight low level elbow adjustment to avoid collision and the Tip Toes control function also auto implements the Move-to-Floor function. The emotional state is set to Anticipation (0.7) in each of the examples with a complex mixed emotional state used in Examples B and C. In Example B Fear (0.7) is added to the Anticipation (0.7) and in Example C, Anger (0.7) is added. This is to illustrate the use of mixed complex emotional states. Example A is given as a reference to the changes occurring in Examples B and C.



Example A Example B Example C

Figure 6.36 Combined Example (iii)

In Example B where Fear is added to the Anticipation of Example A the main area of movement is the arms and legs. Both are brought inward toward the body as protection . The lowering of the back is also increased to complement and re-enforce the general movement inward. In Example C where Fear is replaced by Anger the posture change from that of Example A is upward in direction. The head and arms are raised reflecting this.

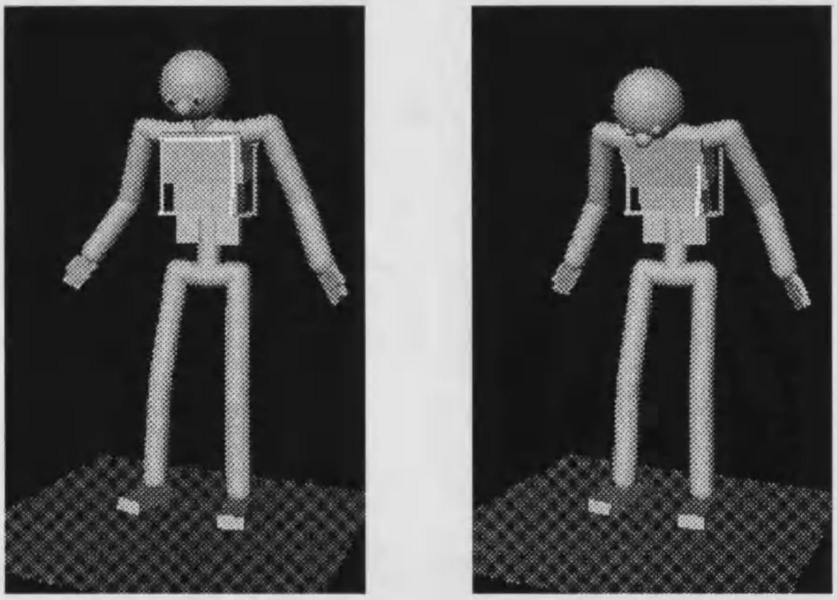


Example A Example B

Figure 6.37 Combined Example (iv)

Combined example (iv) in figure 6.37 shows a general Surprise posture, in each example mixed with another different basic emotion. The general posture is made up from the high level controls Open / Close Stance (0.7), Raise Back (0.75), Raise Leg Right (0.35) and Raise Head (-0.4). The negative value of Raise Head is used in conjunction with a positive value of Raise Back to position the head facing forwards. In Example A the emotional state is Surprise (0.7) and Joy (0.5), in Example B the Joy is replaced with Fear (0.5). The overall effect of the change in emotion is to make Example B more rigid and frozen. There is more movement implied in Example A. The effect of Surprise is shown in both cases with the general movement backward, but the movement in the back and right leg are different.

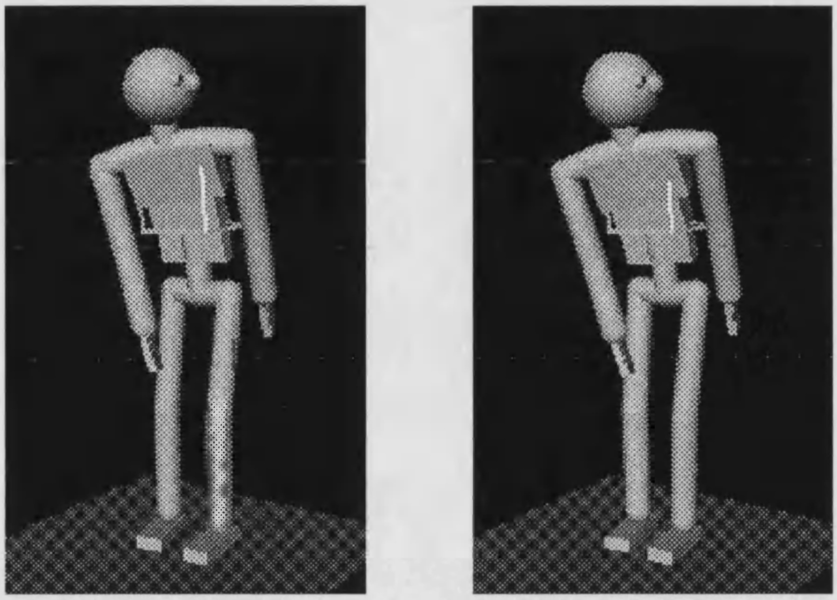
Combined example (v) in figure 6.38 shows a examples of complex Acceptance emotional states applied to a mixed posture. The high level controls used are Open / Close Stance (0.5), Lower Back (1.2) and Shrug (0.35). The emotional state in Example A is Acceptance (0.7) and Joy (0.5), in Example B the Joy is changed to Anger (0.2) and Fear (0.4). The overall change in posture is from a largely open and positive stance to a lowered and more negative pose. The Fear and Anger affect the posture as a result of increased tension, tightening the shoulder and back joints, bringing the arms backward.



Example A Example B

Figure 6.38 Combined Example (v)

Finally combined example (vi) is a general posture of Disgust using the Turn Toward and Look At directed control functions. The high level control values used are Open / Close Stance (-0.3), Forward / Back Stance (-0.5) with Turn Toward and Look At combined to position the back and neck joints. The Turn Toward and Look At directed control functions are used to turn the figure away from the front. In Example A the emotional state is Disgust (0.7) with Anger (0.5), in Example B the Anger is replaced by Fear (0.5). The effect is the subtlest of the examples given in this section as it operates largely on the low values in stance control. The effect of the change of emotion is shown mainly in the leg and arm areas, which are both brought inwards toward the body in Example B.



Example A Example B

Figure 6.38 Combined Example (v)

Chapter 7 Animation Implementation

7.1 Introduction

This chapter details the second part of DEGAS, the animation implementation of the system. Once the key-frame postures are set-up using the posturing system the animation system is used to give the static poses life. The animation process is designed with a similar structure and basis to the posturing implementation. As with the posturing system the importance of emotion and animator input is carried throughout the process.

The set-up of an animation is based on the same ideas of general specification through high level control, connected to the emotional state, and low level fine tuning control of the end result. The differences between the structure of the animation process and the posturing process are mainly in dealing with dynamic, rather than static, elements. The control of the animation is through configurable spline curves. This choice of control through its definition and use is an important element of the animation system. Basic control splines can be set-up according to emotional state information and the joint angles which they will act upon. Then the animator can adjust and fine-tune the splines to their requirements. As with the posturing system the open definition of the animation control allows many interesting possibilities and effects.

The emotional interaction in the animation process is again defined by innate emotional aspects of body language and movement. There has been extensive investigation into automatic initialisation of control splines dependent on the dynamic emotional state. This initialisation takes into account the dynamic emotion state and the joint angles to which it is applied, producing an appropriate control curve. Again the restrictions of knowledge and ongoing research in this area are taken into account. Thus the set-up of splines is intended as a starting point from which the animator can create their animation.

Traditional animation techniques are discussed in relation to the implemented animation system. As with the posturing system these methods can play an important part in emotional animation. Exaggeration, anticipation and timing can be utilised to help the animator achieve their aims. Composition and the use of colour take on new possibilities when their implementation becomes dynamic. A dramatic change in the camera angle or in the colour of a scene can greatly affect the emotion expressed by an animation, and also that experienced by the viewer.

The development of DEGAS has been a large task and as such time constraints have meant that parts of the animation implementation are not as well developed as the posturing implementation. As the animation system depends greatly on the input of the posturing system the latter was made a priority. The animation system is designed as a test bed for implementation of the emotional interaction theories already applied to the posturing system. As such much of the work on the animation system has been in investigating methods and theories in this area, and designing the system such that the theories could be implemented.

This chapter consists of six main sections. The first is an assessment of what is needed in an emotional animation system, based on the psychological emotional theories and in keeping with the structure of the posturing system. This is complemented by a discussion of emotional movement and justification of the approach taken by DEGAS. The third section details the technicalities of the animation implementation of DEGAS. Examining the set-up, definition and adjustment of an animation. The fourth section looks at how the emotional theories discussed previously apply to the DEGAS system. How emotion affects the definition of animation and an examination of the techniques possible. The fifth section details the use of traditional animation techniques and other methods to enhance the impact and flow of an emotional animation. The final section looks at examples of animation created by DEGAS using the methods and techniques discussed.

7.2 Animation Control

This section discusses the requirement of control for an emotional animation system, based on a similar approach to the posturing system. The control of animation in DEGAS between key-frames is through control splines which are linked Bezier curves. The choice of Bezier curves for this purpose, and the restrictions placed on their definition, are justified in the context of the system requirements. Strictly speaking a standard Bezier curve is not a mathematical spline, the term 'control spline' is retained from development where several types of curve were considered. The system of definition and use of the control splines is such that a change to a different type of curve is an option still available. The use of Bezier curves means animation can be smooth with intuitive definition and control. The restrictions placed on the definitions, detailed below, provide good continuity with allowances for emotional interaction in the process.

7.2.1 The Requirements of Control

When considering what sort of control to use for the animation system there were four key requirements and considerations.

- Ease of use
- Definability
- The Emotional interaction
- Arithmetic operations on single or multiple controls

The basis of these requirements led to the use of definable splines or curves to control the motion of joint angles between postures.

The ease of use is very important. The animation control should be clear to the animator in how it works and can be adjusted. This requirement suggested that a spline control would be appropriate. It can be displayed in simple visual terms and can show instantly any adjustments made to its definition. The use of splines provides flexible and definable controls for the animator.

Definability is also an important factor in terms of user interaction. A spline is defined by a set of points which have a clear effect when adjusted. It is an essential part of definition that when a value is adjusted the result and reason of change is clear to the user. In this way the animator can clearly make changes to the control splines to suit their requirements. The flexibility of what is achievable through spline definition is also an important issue. A large variety of movements is made possible by even the simplest of splines with only a small number of defined points.

The emotional interaction with the motion control is an integral part of the system. The emotional state has to interact closely with the shape and definition of the control splines. This is made possible through adjustment of basic spline shapes according to the emotional states associated with the key-frames of the animation. By changing the control points of a spline the shape can be subtly changed to suit the emotion being expressed.

The use of arithmetic operations, such as addition and multiplication, on motion controls is an important consideration linked closely with the emotional interaction. As the emotional state is defined by the eight basic emotions there is a requirement to weight and mix the emotionally defined control splines to provide for complex emotions. By placing certain restrictions on the definition of the control splines these objectives may be achieved.

7.2.2 Bezier Curves

There are many types of parametric curves which could be used in the animation system of DEGAS. The decision to used Bezier curves was based on the requirements of the system detailed above. Bezier curves provide an intuitive and flexible method of control.

A Bezier curve is a specific form of a parametric cubic curve. A standard parametric curve is defined in 3D by the equations in figure 7.1. As the curves will be defining the transition of a joint angle from one value to another, we are only concerned with the 2D representation defined by the first two equations in x and y. Where x will represent time, and y the joint angle.

$$
\begin{aligned}
x(t) &= a_x t^3 + b_x t^2 + c_x t + d_x \\
y(t) &= a_y t^3 + b_y t^2 + c_y t + d_y \\
z(t) &= a_z t^3 + b_z t^2 + c_z t + d_z \qquad\qquad 0 \leq t \leq 1 \\
Q(t) &= [\, x(t), y(t), z(t) \,]
\end{aligned}
$$

Figure 7.1 Standard Parametric Curve Definition

A simple Bezier curve, shown in figure 7.2, is defined by two end points, P_0 and P_3, with two control points, P_1 and P_2. The resulting curve passes through the end points and its direction is defined by the control points. This can be an intuitive representation for the animator and not as confusing as some other spline representations. This means the user can define specific points for the curve to pass through, then, by adjusting the control points, define how the curve passes through them.

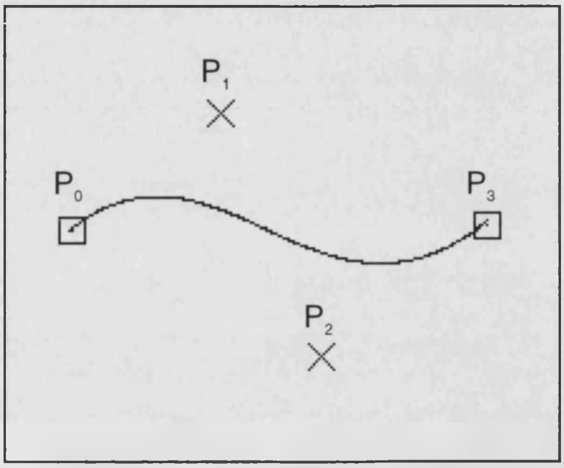
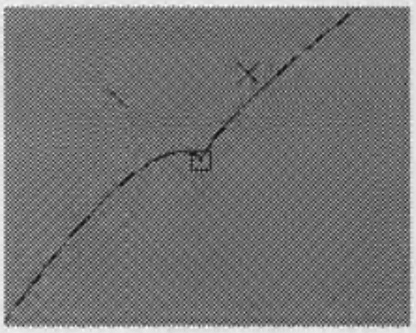
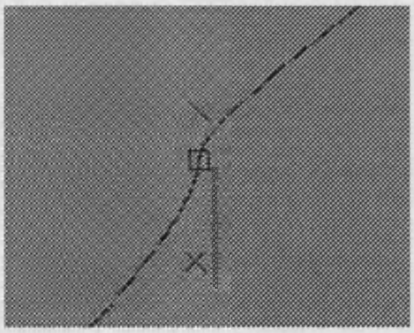


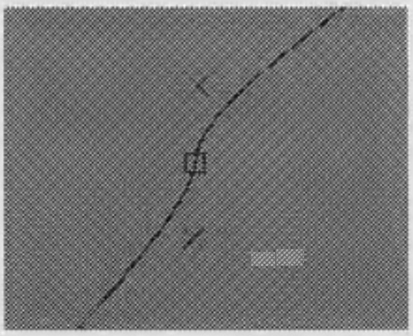
Figure 7.2 A Simple Bezier Curve



Example A



Example B



Example C

Figure 7.3 Bezier Curve Examples

A longer curve is constructed piecewise of a series of simple curves, linked by common points and, for the purposes of continuity, connected control points. Figure 7.3 shows three examples of the connection of two Bezier segments, each with varying degrees of continuity. Continuity between segments at a join can be described as degrees of geometric continuity, G^n, and parametric continuity, C^n. For the lowest level of geometric continuity, G^0, the two segments must join together. For Bezier curves this requirement is achieved by making P_1 of a curve segment the same as P_4 of the previous segment. This is true of all three examples in figure 7.3. For G^1 continuity of two segments the directions, but not necessarily the magnitudes, of the tangent vectors at the join must be in the same direction. That is, one must be a scalar multiple of the other. This is true of example B in figure 7.3, but not of example A. For C^n continuity the direction and magnitude of $d^n/dt^n[Q(t)]$ through the nth derivative must be equal at the join point. Thus for C^1 continuity the tangent vectors at the join must be the same in terms of direction and magnitude. This is shown only by example C in figure 7.3.

It is obvious that G^0 continuity is essential for the use in the animation system, but what about G^1 and C^1 continuity? The joining of curve segments occurs in a transition between key-frames. This means that no large direction changes should be needed and it would be useful to have as fluid a transition as possible. Thus for DEGAS it has been made a requirement that C^1 continuity is maintained throughout the control curve. This does place some restrictions on what is possible, but allows for smooth transitions between key-frames. Due to the nature of how the curves are interpreted this is not as restrictive as it may appear. These issues are discussed further in Section 8.4.

7.3 Emotional Interaction in the Animation Process

Emotional interaction in the animation system of DEGAS uses more subtle techniques than those in the posturing system. It is based on the same principles of basic set-up of control, adjusted by the emotional state, further definable by the animator. The difficulties associated with definition of emotional interaction in the posturing processes are present again in the animation system, with the added problem of dynamic change. Translating basic descriptions of emotional effect on the body and movement from psychological theory to effect in the animation has been a complex task. As with the posturing system the emotional interaction has been defined as an exploration of the theories presented by psychology and other sciences. As such the interaction is subtle in nature and intended to be adjustable by the animator if it does not suit their requirements.

With the posturing system there was user definable control over the effect and extent of emotion interaction. As the animation system has not had as much development time as the posturing system there is less control over the initial set-up of control spline sets. The user interaction is purely based on adjustment after the spline sets have been defined. This lack of user control is offset by the carried through effect of user definition in the posturing system.

Figure 7.4 shows how the animation process is designed. By comparing this to figure 5.6 it also shows how the animation approach relates closely to the posturing process. The major differences are in the use of dynamic rather than static values. The main input is a sequence of static postures. The interpretation and construction of control splines is related to the dynamic emotional state, dynamic constraints and traditional animation techniques, with fine tune control from the animator.

The basic interpretation and creation of control splines for an animation is dependent on three main factors. The emotional state in terms of experienced emotion, the emotional state in terms of intensity of experienced emotion and the joint angle or degree of freedom to which the control spline will be applied. It is important to remember that the control splines are reflecting the emotional effect on movement in speed and direction between postures. While it could be used to alter the nature of the movement this is avoided and is better handled through the posturing system.

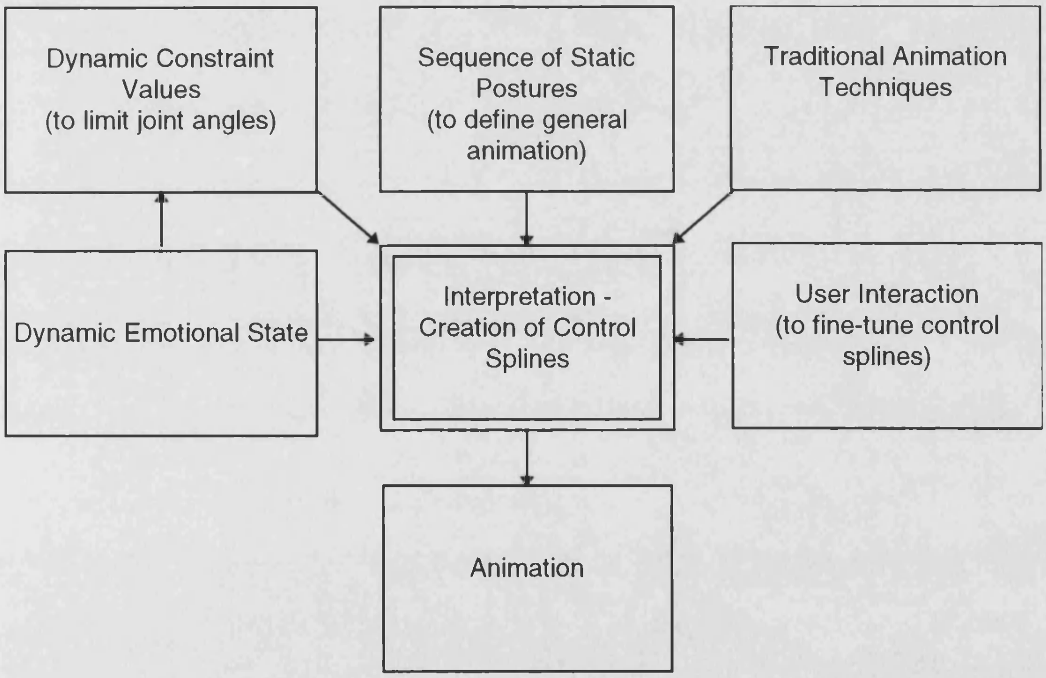


Figure 7.4 Animation Process

Before looking further at the interpretation process it is necessary to examine the emotional effect on body movement, how movement changes with experienced emotion and intensity.

7.3.1 Emotional Body Language in Movement

In order to understand the connection between the animation system and the basis of emotional interaction it is necessary to examine the emotions, and in particular the emotional model used by DEGAS, in terms of the effect on body movement. With the posturing system the emotional effect was largely connected to positive and negative implications of the defined emotion. In the animation system that effect is lessened and the main contributors to the emotional interaction are the intensity of the emotion and the defined emotion itself. [48]

As with the posturing system it is important to remember that the basis of the emotional interaction, the research and theories in body language and emotional expression, are not exact sciences. The emotional interaction in the animation system has to reflect this by being flexible and definable.

7.3.1.1 Tension and the Intensity of Emotion

Tension and the intensity of an emotion play a large part in how a motion is carried out. The two are also linked in that you can imply a certain level of tension from the level of the emotional state. By looking at the two extremes, high tension and intensity and low tension and intensity it is possible to extrapolate some general rules associated with their effect. When tension or emotional intensity is high the movement becomes more rigid, and robotic [46, 47]. Transitions are closer to a uniform motion with little variation in speed of movement. Depending on the actual emotion being experienced the overall speed of movement becomes generally quicker and more immediate. When tension or emotional intensity is low the muscle tone is lower, hence movement becomes sluggish and slower. Motion of arms and legs is as a result of a larger effort at the beginning tailing off toward the end, thus while overall speed is slower it is may be more rapid at the start of the motion. Variation in speed during the motion is much greater than in higher tension movement. While tension itself in not modelled specifically in the animation system, its affect is taken into account as implied by the emotional state.

7.3.1.2 Positivity and Negativity

While the effect of positive and negative aspects of the emotional state is less in the animation system than in the posturing system, there are still some general rules which can be applied. These rules must also be combined with emotional state and tension considerations, so there will always be exceptions to these guidelines. Positivity can be shown by quicker more direct movement. Goal directed movement will be efficient and uniform across the joints. Negativity can be shown through slower movement depending on the emotion being expressed and the tension associated with it. The goal directed movements are less direct and non-uniform [46, 47]. As examples consider first a very happy figure. This is positive which combines with the joyous emotion to produce movement which is sprightly and directed. Now consider a sad figure. This is negative which combines with the lower tension associated with sadness. The movement is slow, sluggish and non-uniform.

7.3.1.3 Timing

Timing is an important issue in relation to emotional movement. It has significant connections to emotional intensity and emotional state. In the following examples the overall time frame, the length of the whole transition, is discussed but not displayed on diagrams so direct comparison of shape can be made between emotions. As implemented in DEGAS the time frame can be set by a separate weighting value which determines the frame rate, curve sampling rate and subsequent speed of the animation. The timing issues separate to the overall time frame are discussed and shown in the diagrams. The faster movement within a time frame is represented by a steeper gradient on the curve.

7.3.1.4 Discussion of Basic Emotions

The most basic movement used in animation is the slow-in, slow-out control spline. This gives a much more natural looking motion when applied between postures than a linear interpolation. It is easiest to discuss the effect of the basic emotions on the motion of a figure by referring to the slow-in, slow-out shape, though the basic theories involved can be applied to any control spline. A good example of a basic slow-in, slow-out curve is shown by spline A in figure 7.7.

7.3.1.5 Joy

The basic emotion Joy is associated with quick and lively movement. The motion should be sharp and clear. The effect on the basic slow-in slow-out control spline is most noticeable at the end of the transition. Here the motion ends quickly to give the movement a feeling of life and enjoyment.

Though the motion is generally quicker, this is also linked strongly to the intensity of the experienced emotion. If the emotional state is joyous but low in intensity then this should not result in rapid movements. This represents a more content feeling. However the general rules of increased movement toward the end still apply.

The effect of joy in relation to specific joint angles and areas is connected to how joy is expressed more generally. The motion of limbs is an area where there is greater movement and hence greater possibilities of expression through movement. When people are happy they often express this with exaggerated arm and leg movements. This reflects the feeling of wanting to express the emotion to others and enjoy the release of emotion. Common movements associated with joy, jumping, waving arms and the use of energy, illustrate this. This means that the control splines for the arm and legs joints should be affected more than the torso joint angles.

The sample control spline A in figure 7.5 shows some of these theories in use. The differences from the standard spline are shown by the movement of the third main point of the curve to a lower position to cause an increase in the movement rate at the end of the transition.

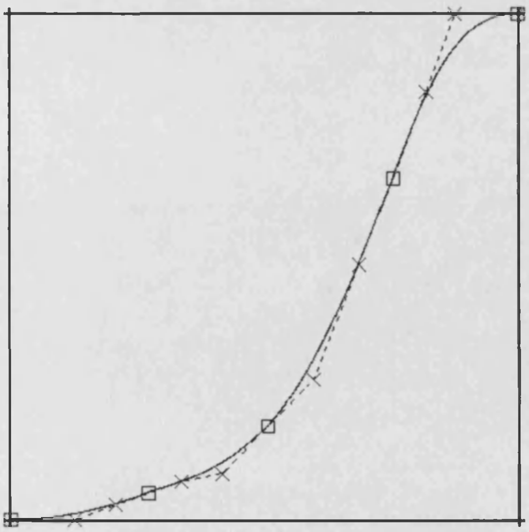
7.3.1.6 Sad

The basic emotion Sadness is associated with slow and lifeless movement, being the opposite of Joy. The movement is sluggish and because of a loss of muscle tone, lacking in enthusiasm. As with Joy the effect on the basic slow-in slow-out curve is most noticeable at the ends. The movement is faster at the beginning reflecting an early amount of effort on the part of the figure, tailing off and slowing at the end of the movement.

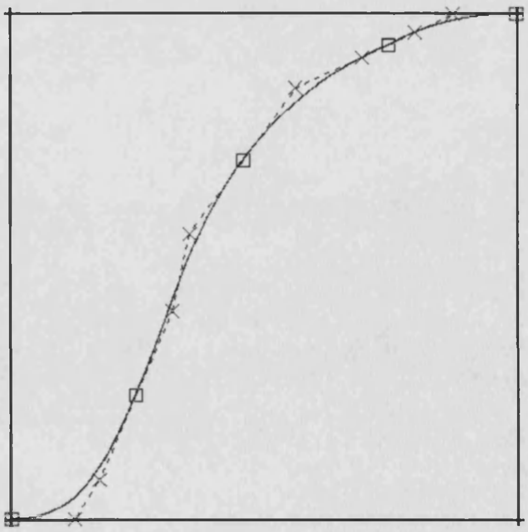
The effect of Sadness with respect to time is to generally slow the movement down, increasing the time frame. This re-enforces the sluggish motion and again is as a result of the loss of muscle tone and enthusiasm.

As with Joy the areas of greater expression are the limbs, but also the head. The head is especially effected by Sadness as the muscle and tension factors will cause it to move more and hence express the emotion more clearly.

The sample control spline B in figure 7.5 shows a Sad movement curve. The second and third main points are adjusted upward to increase early movement in the time frame. This has the resulting effect of slowing the rate of movement at the end of the motion.



Spline A Joy



Spline B Sadness

Figure 7.5 Sample Control Splines Related to Joy and Sadness

7.3.1.7 Anticipation

Anticipation is a gradual and carefully movement. Motion is closer to uniformity than most movement because of increased muscle tension. The effects on the slow-in slow-out curve are to generally bring the shape closer to that of a straight line, slowing at the end as the anticipation comes closer to a climax.

The time frame of Anticipation is increased to reflect the care taken with the movement. No sudden movement is shown as the feeling of expectancy is usually before a sudden movement in response to the cause of the anticipation. The increased time frame can also help re-enforce the expression because the anticipation is reflected in the viewer, who has to wait and think about what is about to happen.

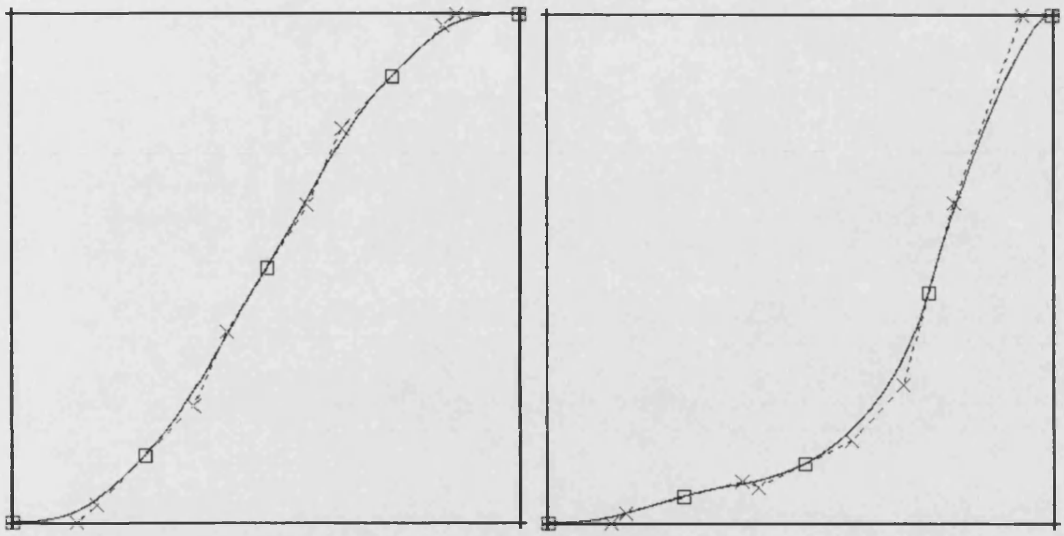
The effect of anticipation is uniform across the body because of the increased muscle tone. Hence all joint angles should move at a similar rate. Control spline A in figure 7.6 shows a sample anticipation control spline. The second and fourth main points are adjusted to make the shape closer to the simple straight line control spline. The control point associated to the left of the final main point is moved to slow the movement down as the transition ends.

7.3.1.8 Surprise

Surprise is associated with rapid and abrupt movement. Motion is affected by a rapid increase in muscle tone and sharp quick movement results. The abruptness can be simulated by adjusting the slow-in slow-out curve to end more sharply than it began.

The time frame for surprise is greatly reduced and is a major factor in expression of this basic emotion. The increase in tension causes the muscles to tense quickly, resulting in rapid movement. The shortened time frame will have a dramatic effect across the body, especially in areas where large movement is possible, such as the arms and head.

An example Surprise control spline is shown in figure 7.6, spline B. The shape itself does not show the time effects, as this is provided for in the weighting. The sharper finish to the movement is done by adjustment of the third and fourth main points to increase the gradient at the end. The control points are adjusted to smooth the curve to complement this general shape change.



Spline A Anticipation Spline B Surprise

Figure 7.6 Sample Control Splines Related to Anticipation and Surprise

7.3.1.9 Acceptance

Acceptance causes a uniform motion curve, smooth and deliberate. The basic slow-in slow-out curve is representative of this, with a slight slowing in the later halve of the movement to show openness. There is no abruptness or unnecessary quick movement as acceptance is a friendly expression.

General timing for Acceptance reflects the openness and positive feeling. It is not a fast or slow motion, but somewhere in the middle ground. Rapid or too slow motion applied when acceptance is being displayed can destroy the emotion. That could give messages of hastiness or caution when used with accepting postural elements.

The accepting motion should be applied throughout the body uniformly. This again re-enforces the emotion being expressed and means it is not complicated with other conflicting messages. The control spline for Acceptance is very close to the general slow-in slow-out curve. Only minor adjustments may be needed. An example is shown in figure 7.7, control spline A.

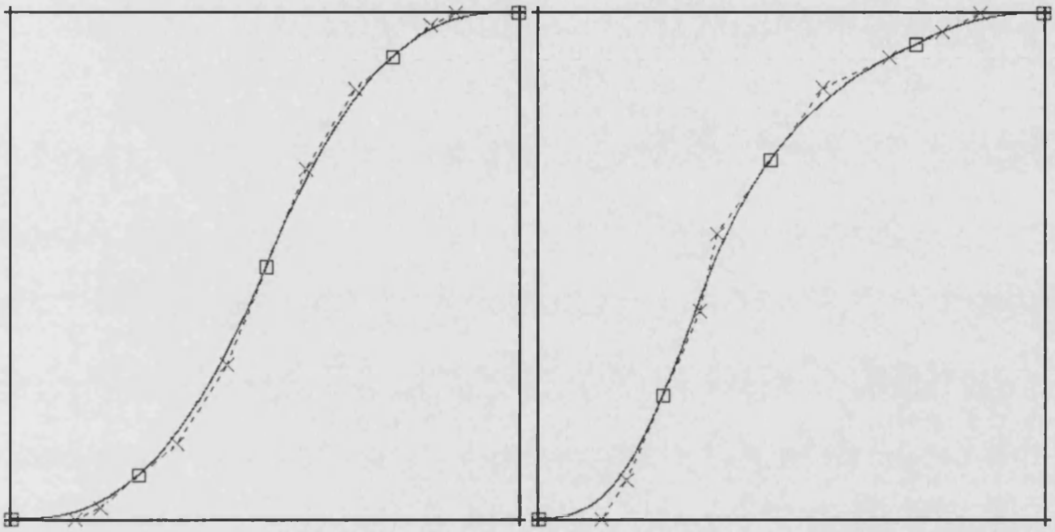
7.3.1.10 Disgust

Disgust causes a sharp initial movement to express the feeling, slowing toward the end of the motion. This follows from the associated increase in muscle tone and subsequent gradual reduction.

The general timing for Disgust can vary dependent on the level of disgust and the situation to which it is applied. Subtler uses can be longer and more drawn out. More direct application will result in a quicker overall movement, reinforcing the expressed emotion.

Disgust is primarily shown in the head with secondary influence in the legs and arms. This is because the head is most effective in showing contempt by turning away from the cause of the emotion. Effects in the arms, legs and to a certain extent the back are used to reinforce the feeling, but the motion is more subtle and less abrupt.

Figure 7.7 shows a sample of Disgust in control spline B. It shows a rapid initial movement caused by raising the second main point and a resultant slowing toward the end of the motion. The control points are adjusted to smooth the changed curve.



Spline A Acceptance Spline B Disgust

Figure 7.7 Sample Control Splines Related to Acceptance and Disgust

7.3.1.11 Fear

The movement associated with fear is largely to do with timing, related to the level of emotional state. The shape of the curve though is defined by the increased tension in a similar way to anticipation. The motion is stiff and robotic because of the change in muscle tone.

The time frame is closely related to the level of fear being experienced by the character. Generally the higher the level of emotion the faster the associated movement. There can also be other important factors involved due to emotion mixing.

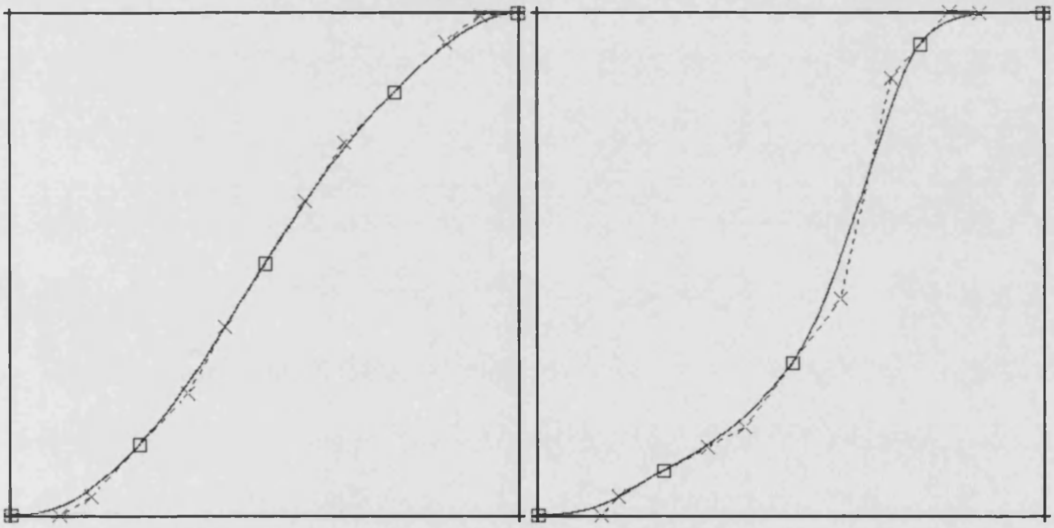
Fear is an emotion felt through the whole body, caused by a general increase in tension and muscle tone. Therefore the basic shape of curve could be used for all joints. Spline A in figure 7.8 shows a sample control spline for Fear. It is similar in shape to that of Anticipation, but does not slow toward the end. The shape is close to a straight line with slight slow-in, slow-out properties at the ends.

7.3.1.12 Anger

Movement associated with the basic emotion Anger is sharp and abrupt, similar to that of Surprise. Increase in muscle tone is linked to the level of emotion state, so the greater the anger the more tension experienced. This links the level of Anger to the level of abruptness and speed of the movement. The basic shape is slow to start, building to a faster motion which ends abruptly.

Time is similarly linked to the level of emotional state, being quicker with more intense feelings of anger. The areas where anger is felt most are the extremities where expression can relieve some of the feelings. For example swinging of arms, kicking the air or other objects.

An example control spline associated with Anger is shown in figure 7.8, control spline B. It starts with the usual slow-in associated with a standard slow-in slow-out curve. This develops by the third and fourth main points to an increased gradient which ends abruptly near the fifth main point. The short pause at the end of the curve can serve to contrast with and bring out the faster abruptness of the initial movement.



Spline A Fear Spline B Anger

Figure 7.8 Sample Control Splines Related to Anticipation and Surprise

7.4 Set-up of an Animation in DEGAS

This section is an introduction to how an animation is set-up in DEGAS and what is required. An animation in DEGAS is defined by a sequence of two or three key-frames. In the case of two frames the animation is from the first, to the second. With three frames the animation is from the first, to the third, through the second. The separate key-frames can have different emotional states, so the emotion at each posture is static, but in the animation it is dynamic.

This enables short animation sequences to be created, from which longer animation may be constructed. In the context of the testing of the emotional theories and basis of this research it is more than sufficient.

7.4.1 Using Two Key-Frames

The simplest mode for the animation system is the two key-frame option, where the resulting animation is from the first frame to the second. This allows simple movements and transitions to be defined and created. The transition between the two key-frames is controlled by a single set of control splines, which are discussed in more detail in the following sections. This method can be restrictive in what the animator is able to produce, but the option is provided as it is easier to use to construct simpler movements. As the movement is essentially quite plain it allows the animator to concentrate on finer detail within the movement. The time control for the two key-frame method is based on a set time frame which can be adjusted by a sliding weight value. This means it is possible to preview the animation at various speeds.

7.4.2 Using Three Key-Frames

The second of the two modes for animation set-up is the three key-frame option. This is where the animation is from the first frame to the third, through the second. This technique allows for more complex movement than the two key-frame method. It also allows the animator to ensure the continuing transition, that from the second frame to the third, is smoother and fits their requirements. This is made possible by the use of two sets of control splines which are defined separately for each transition. Thus one set can be defined and used for the transition from the first to the second posture, and one set for the transition from the second to the third.

When longer animation is created with the two key-frame method the joins of the separate sections can be obvious where the animator would prefer them to be smooth. With the three key-frame method the animator can be sure that important transitions are smooth before they are saved to a file. It also allows the creation of single movements which are more complex than the two key-frame method allows. For example consider the movement of raising the arms above the head. There is a multitude of ways that this simple motion can be carried out. When using the two key-frame method there is limited control over exactly how this occurs, and while a variety of different motions are possible the definition is sometimes difficult. With the three key-frame method the animator can set a middle position for the arm approximately half raised. This then gives more definable control over how the arms are raised. It would of course be possible to define the same movement using the two key-frame method twice and joining the two created movements together. However the three key-frame method allows the animator to ensure the transition through the mid posture is fluid and correct.

Time control for the three key-frame method is similar to that of two key-frames. Here there are two weighting values for the time frame. Thus the time for the transition from second to third frame does not have to be the same as that for the transition from first to second.

7.4.3 Emotional Input

The emotional input to an animation sequence is derived from the emotional states of the static postures. From this information the dynamic emotional state can be determined at key stages in the animation. This then affects the form and structure of the control splines. This means that the animator does not give any further emotional input to the system other than through the static postures. It is intended that once control splines are set according to the emotional state the animator could then adjust them to suit their requirements.

7.4.4 Creating the Animation

Once a simple animation is defined by the two or three key-frames and a set of control splines then the movement can be previewed in real-time. This means any adjustments the animator wishes to make can be made and the effect can be seen immediately. This is important so the creative process is not interrupted by lengthy set-up procedures. Once the animator is happy with an animation it can then be spooled to a data file and played back at a later date using the spool player program. The animator can then adjust the defined postures and add to the spool with more animation. As the spools are text files, longer animation can be made by concatenating spool files. This means a spool file which ends in the same posture as another begins can be joined to produce a longer seamless animation.

7.4.5 Design

From the beginning the animation implementation has been designed to be as flexible as possible, whilst adhering to the requirements of the system. This base has been refined by restrictions to create the current system, though in many areas, such as the definition and user interaction of control splines, there is still a large amount of possible variation. The majority of the restrictions on the animator are stated but not always implemented fully in the system. This means the system will allow the user to go beyond the normal boundaries of use with possible unexpected results. However, it also allows for changes in the structure of the animation system, and the restrictions placed on the animator.

7.4.6 Use and Adjustment of Control Splines in DEGAS

The control spline editor provided is simple but effective in use. A sample spline is shown in figure 7.9. The points on the control spline are shown as a dot surrounded by a square, the associated control points are connected by a dashed line and represented by a cross. To indicate the basic shape the sequential control points are also linked by a dashed line. This re-enforces the structure of the control spline and the connections between control points of subsequent points of the spline. The spline itself is shown as a solid line through the main points.

The outer limits of the control spline area are defined by solid lines, with the horizontal x-axis representing time and the vertical y-axis representing the difference between the start and end positions of the associated movement. Thus the lower left-hand corner of the graph represents the point where time is zero and the position is that of the initial key-frame. The top right-hand corner represents the point where the time frame ends and the position of the final key-frame. The time value should always be increasing, though as the system stands it is possible to define a control spline which does not follow this rule. In these cases the system always uses the appropriate curve segment definitions, but sharp jumps in movement will be evident.

To edit a particular control spline a user simply clicks in the main drawing area within the defined control spline area with the left mouse button. If the mouse press does not hit a previous point on the current control spline then a new point is inserted into the curve. The control points associated with the point are automatically generated in a standard position from which the animator may adjust them to their requirements. To maintain the requirement that control points are inserted in time sequence all points are stored in a linked list. When a new point is added it is inserted in the list between two points, one with a time greater than the new point, one with a time less than the new point.

If the animator clicks on a point already defined on the control spline then that point is deleted from the curve. A replacement may be then be added where required. If a control point is selected then it must then be repositioned before further editing can occur. To maintain C^1 continuity when a control point to the left of a main point is adjusted this automatically adjusts the control point to the right, and vice versa. This means that the distance and direction of control points from the associated main point are the same but in opposition to each other. This can be seen clearly in the sample spline in figure 7.9.

Added main points on the control spline must be defined within the limits defined by the solid straight lines. The associated control points can be defined outside this area however. This means that the control points can be adjusted so that the control spline is defined outside the upper and lower limits of the position value. This is useful for reasons discussed in the Traditional Animation Techniques section.

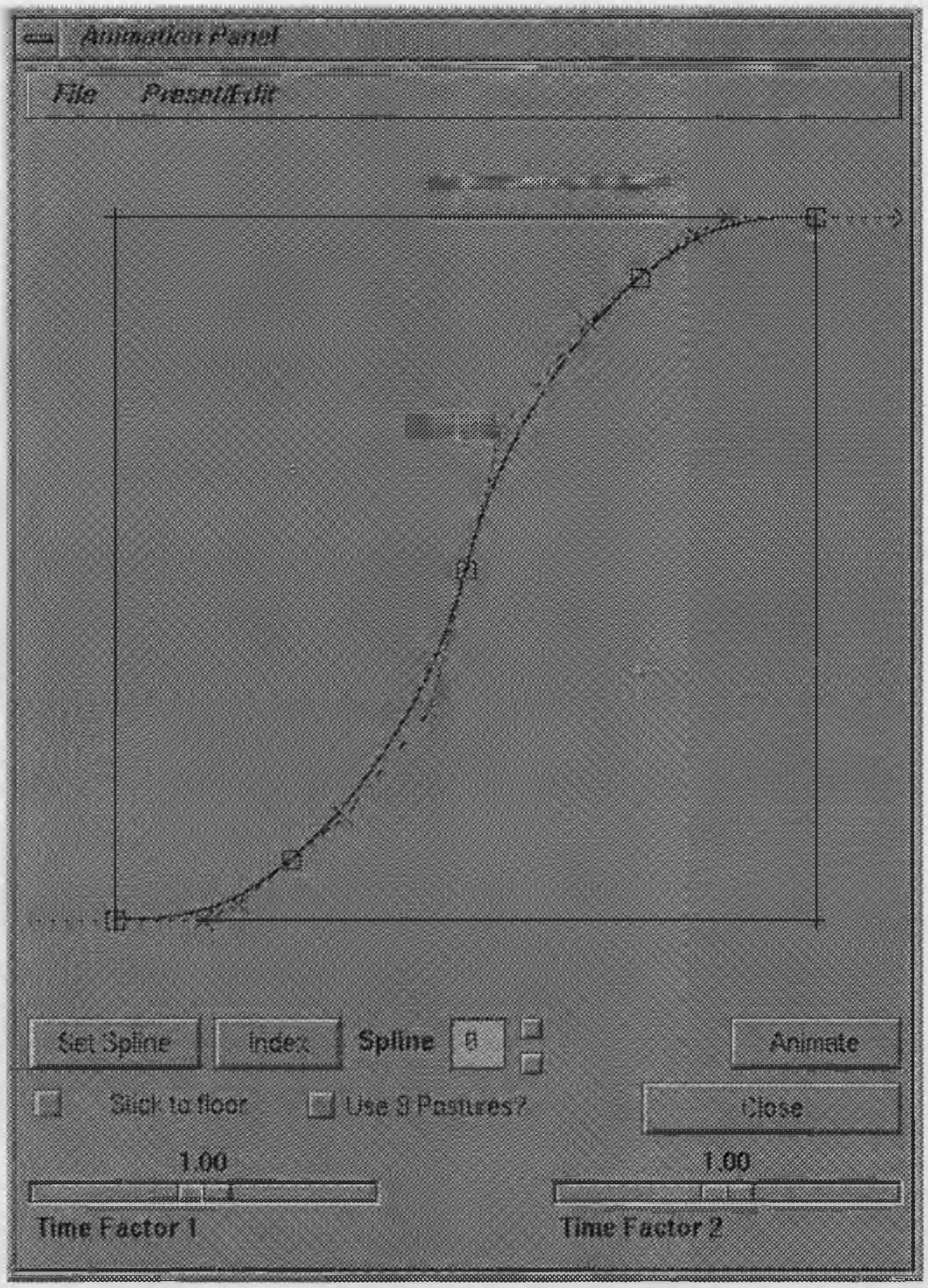


Figure 7.9 A Sample Control Spline as Displayed by the Editor

The values of the control spline definition in terms of time and movement are internally limited from 0.0 to 1.0. In the case of position the value 0.0 represents the initial key-frame position and 1.0 the subsequent key-frame position. In the case of time the values represent the relative transition in the time frame, which is adjusted by a time factor to give the actual time of the animation. For an animation from one key-frame to another the time value goes from 0.0 to 1.0 in steps defined by the appropriate time factor. The animation time step is equal to (0.05 / time factor). Therefore if the time factor is set at 1.0 then the animation time step is 0.05, which gives 21 frames of animation. If the time factor is set at 2.0 the animation time step is 0.025, which gives 41 frames of animation. If the time factor is set at 0.5 the animation time step is 0.1, which gives 11 frames of animation. The time factors can be set by using the sliders shown at the bottom of the control spline editor, figure 7.9. There are two definable time factors, the first applying to a transition between frames one and two, and the second the transition between frames two and three, if used. The values can be set between 0.01 and 2.00 in steps of 0.01.

It is possible to define the position variation ending on a value other than 1.0. For example it could go up to 0.8 and then down rapidly back to 0.0. A picture example of this sort of spline can be seen in figure 7.10, the Bell curve. This means that if this spline were associated with the elbow joint, and in two key-frames the joint started straight and finished bent, then the resulting movement would involve the bending and then straightening of the elbow. This technique can produce a variety of movements, but it should be noted that it has can only be used effectively when using just two key-frames or on the second to third key-frame transition when using three key-frames.

7.4.7 The Set-up and Definition of Control Spline Sets

For each animation transition, one in the case of two defined key-frames and two in the case of three defined key-frames, there is an associated set of control splines. Each control spline defines the transition of one of more joint angle or degree of freedom. The control splines are defined in a spline database which contains up to fifty different splines, then each joint angle or other degree of freedom is linked with a spline in the database through a spline index. All of this information is definable by the animator. Initially the spline database is set to contain identical straight line control curves. These may then be edited by the user or automatically set by the system.

The spline editor can cycle through the control spline database using the two buttons at the side of the spline number, see figure 7.9. The user may make adjustments to any of these as required. Then to confirm any changes to the control spline the button Set Spline must be pressed. There is also an index window which indicates which splines from the database are associated with which joint angles and degrees of freedom. The initial index window relates to the transition from posture one to posture two, used in both two and three key-frame animation. A further button press brings up a second window which relates to the transition from posture two to posture three, used only in a three key-frame animation. The windows contain edit boxes with values relating to the numbered spline index. They are adjustable by simply clicking the boxes and editing the numbers held there.

To help with the definition of the spline database there are useful functions accessible through the top menu bar. Under the Pre-set / Edit header there are facilities to Copy, Paste and Add control splines, and also a number of pre-defined control spline shapes for quick and easy definition.

The Copy and Paste functions make a copy of a spline to use separately after adjustment. First a spline is selected by displaying it. When the Copy function is selected a replica of the spline is put into a buffer storage. Another control spline can then be selected and, by using the Paste function, be replace with the one in the storage buffer. This is useful when the animator wants a particular joint angle to move in a similar but not identical way to another. By copying the original control spline to another in the database and making appropriate adjustments two separate but similar control splines can be defined. Then the animator can associate the relevant joint angles to the appropriate control splines using the index.

The Add function is similar but more restrictive in how it can be used. An initial spline must first be selected using the Copy function. Then after selecting another control spline and using the Add function the second control spline is replace with an approximation of the two splines averaged. The restrictions placed on this are that each control spline has the same number of main points. This is because the points of each spline are averaged to give the main points of the resulting spline. The associated control points are also averaged in terms of direction and magnitude. As the main points of the control spline are averaged the result is only an approximation to the actual average of the two curves. The accuracy can be improved by ensuring the position of the main points of each spline are approximately equal with respect to time. The pre-defined curves discussed next all fit these criteria as they are all five point curves with equally spaced points.

If the animator wishes to define their own control splines, rather than adjust those automatically generated, there is the facility to start from one of a set of pre-defined curves. Each contains five points equally spaced with respect to time. These are defined as the Straight Line, Slow-In Slow-Out, Bell Curve, Fast-Slow and Slow-Fast. The Slow-In Slow-Out curve is shown in figure 7.9, the others below in figure 7.10. Each is selected as a useful starting spline to be adjusted to suit the requirements of the animator.

The Straight Line control spline is a simple straight line from (0.0, 0.0) to (1.0, 1.0). It provides uniform transition of position with time. The Slow-In Slow-Out control spline is a useful curve often implicitly used in traditional animation [29]. The name is derived from the position transition which starts slowly, picks up speed in the middle, then finishes slowly. It provides a more natural basic curve for general movement. The Bell Curve is a standard Slow-In Slow-Out applied to the principle of transition to the end position and return defined by two key-frames. This has been discussed previously as an interesting method possible using the control spline editor. Here the slow-in slow-out control is applied in the initial and returning transitions. Fast-Slow and Slow-Fast are similar curves defined as a good starting point for specific movement. The Fast-Slow control spline starts with a quick positional transition and slows toward the end. The Slow-Fast control spline starts with a slow positional transition and quickens toward the end.

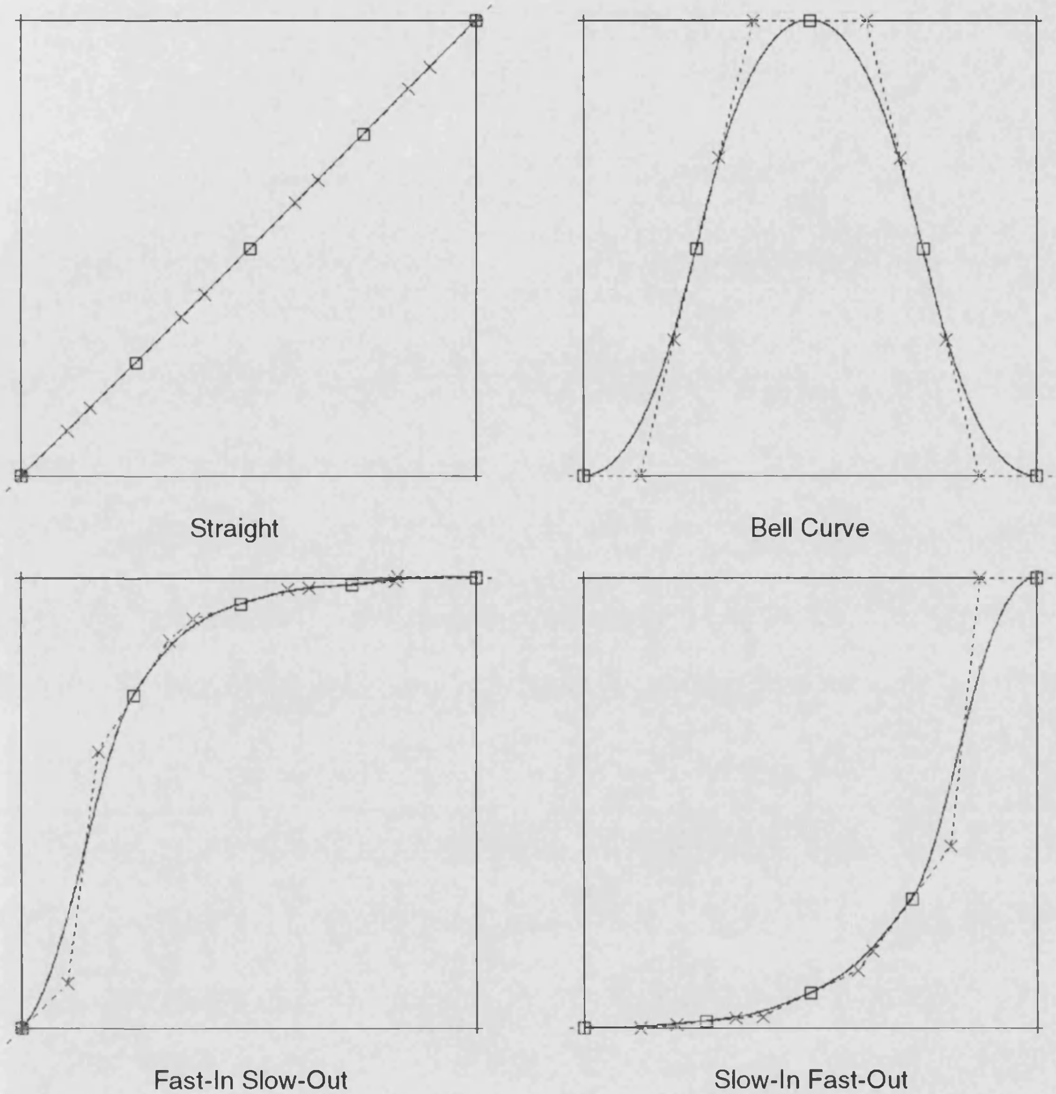
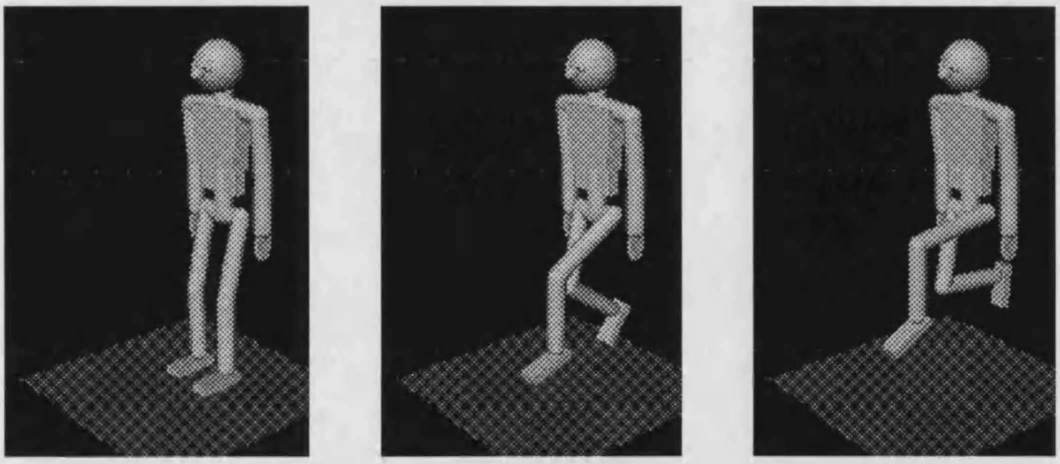


Figure 7.10 Pre-defined Control Splines

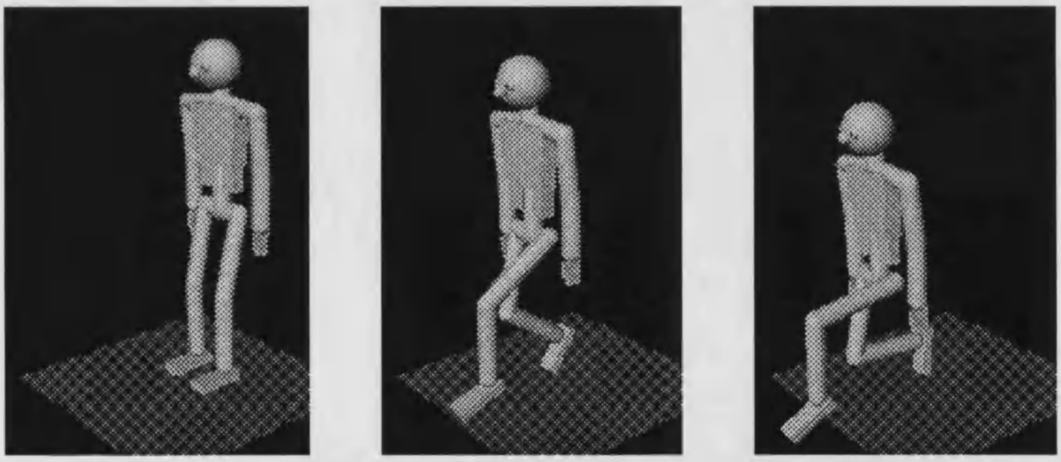
7.4.8 Automatic Translation Adjustment : Keep to Floor

An option while an animation is carried out is constantly to apply the Move to Floor function discussed in Section 6.1.3. This means that as the legs are adjusted the figure remains on the floor maintaining the foot position. When the Keep to Floor button is ticked in the animation window the Move to Floor function is applied at each frame after all other adjustment. This will override any defined translation in the up-down and forward-backward directions. This technique stops the figure from putting its foot through the floor and also maintains the tip of the foot position of the lowest foot so that 'moon-walking', or floating in the air, is negated or reduced.

An example of the Keep to Floor technique is shown in figure 7.11. The figure is shown in two sets of sequences of three frames. In sequence A the Keep to Floor method is not applied, in sequence B it is. Note that in sequence B the lowest foot maintains its position and the figure is translated forwards accordingly, unlike sequence A. The method currently in place does have some problems when trying to maintain a walk cycle covering more than two steps as the figure will jump back to the zero position when the second foot touches the floor. This problem could be countered by defining the figure as walking rather than standing still, and keeping a track of the current transition position.



Sequence A



Sequence B

Figure 7.11 Sequences Demonstrating the Use of Keep to Floor

7.4.9 Spooling

To record the results of an animation DEGAS can spool the raw joint angle and other global values a text file for later playback. The file stores the sequence as a series of floating point values for each frame. This allows for manual adjustment and the concatenation of spool sequences. A program called Spoolplayer is used for the playing back of defined sequences, and offers useful functions for sequence manipulation.

There is great flexibility in using this method for animation sequences. The files can be viewed, analysed and adjusted with a simple text editor, and individual frames may be edited or removed from the sequence. The spool options are simply accessed by bringing up the spool window and clicking on 'Start Spool'. From that point on, until the 'Stop' button is pressed all movement of the figure is spooled to the spool file. To create a simple animation the animator simply sets two or three postures and animates between them. If a longer animation is needed then the final posture of the first sequence should be loaded into the first posture and the second and third postures updated accordingly. Then when animated the sequence is add the end of the current spool file. Separate spools created in this way may also be concatenated successfully if the first spool ends on the same posture as the beginning of the second spool.

The Spoolplayer program allows the playback of spools created in DEGAS. It has useful video playback functionality such as play, pause, stop functions. It also has options to load different spools once running. The command line allows the user to specify the start-up spool to be loaded and the Inventor model file to which the animation will be applied. As animation is spooled as actual joint angle values then the use of a different model than the one used to create the animation can produce unexpected and entertaining results.

A useful feature of the spooling method is that all movement is spooled to the data file. Thus posturing adjustments can be spooled as animation, as well as defined animation using the animation system. This feature was added during testing of high level control functions early in development. It was noted that, because of the real-time update of the figure through posturing adjustment, the animation produced was sometimes interesting and could be of benefit to the development of the system as a whole. Thus the adjustment of single high level control functions or adjustment in the emotional state with no postural values changed can be spooled and analysed in this way.

7.5 The Use of Emotional Interaction With Control Splines

Given the general examination of emotion with respect to control splines it is now necessary to examine how these theories might be applied to DEGAS. This requires analysis of techniques to adjust basic control splines in terms of shape, weighting and addition, to allow the application of the emotional state theories. Emotional control spline adjustment has so far been stated in general terms without reference to specific values and mixing of emotions. This section discusses possible methods and techniques based on testing using DEGAS.

7.5.1 Shape Manipulation of Control Splines

The general rules for emotional interaction can be defined in terms of shape change of the control spline. For example, a reduction in speed toward the end of the movement. How can this be effectively translated to the animation system, and what restrictions may be necessary? If some automatic internal adjustment of a control curve is to be implemented it can help greatly if the generated curve is standardised in some way. By restricting the number of points and the placement with respect to time the requirements of interaction can be met without significantly reducing the flexibility of the curve. The restrictions can also have other advantages when considering mixed emotions which are discussed in Section 7.5.2.

My research in this area has focused on using a five point Bezier curve, each main point equally spaced with respect to time. This breaks down the time frame into four equal sections. Initial impressions are that this would be too restrictive on what is possible within these boundaries. However when considering the restrictions of application, that time be continuously increasing and the time frame covered by the control curve, the restrictions are acceptable. The fact that any automatically generated control curves can be further adjusted by the animator, and that after generation the restrictions no longer need apply, also allows for greater flexibility.

The result of the restrictions means that emotional interaction can now be described in terms of control curve shape adjustment by segment and more readily be applied to a basic curve. A sample slow-in slow-out curve defined by these restrictions is shown in figure 7.12. The main points of the curve are labelled ***A*** to ***E*** with associated control points ***a*** to ***e***. For each main point we need only be concerned with one control point as to maintain C^1 continuity the second is automatically adjusted in accordance with the first. The restrictions have effectively broken down the control curve into particular areas representing time segments. The movement within these time segments is controlled by the placement of the main points either side and their associated control points. This sets the basis for emotional interaction as effects can now be classified in terms of adjustment relative to these set time segments. An emotion where movement slows toward the end can be defined by an adjustment to main points ***C*** and ***D*** and control points ***c***, ***d*** and ***e***.

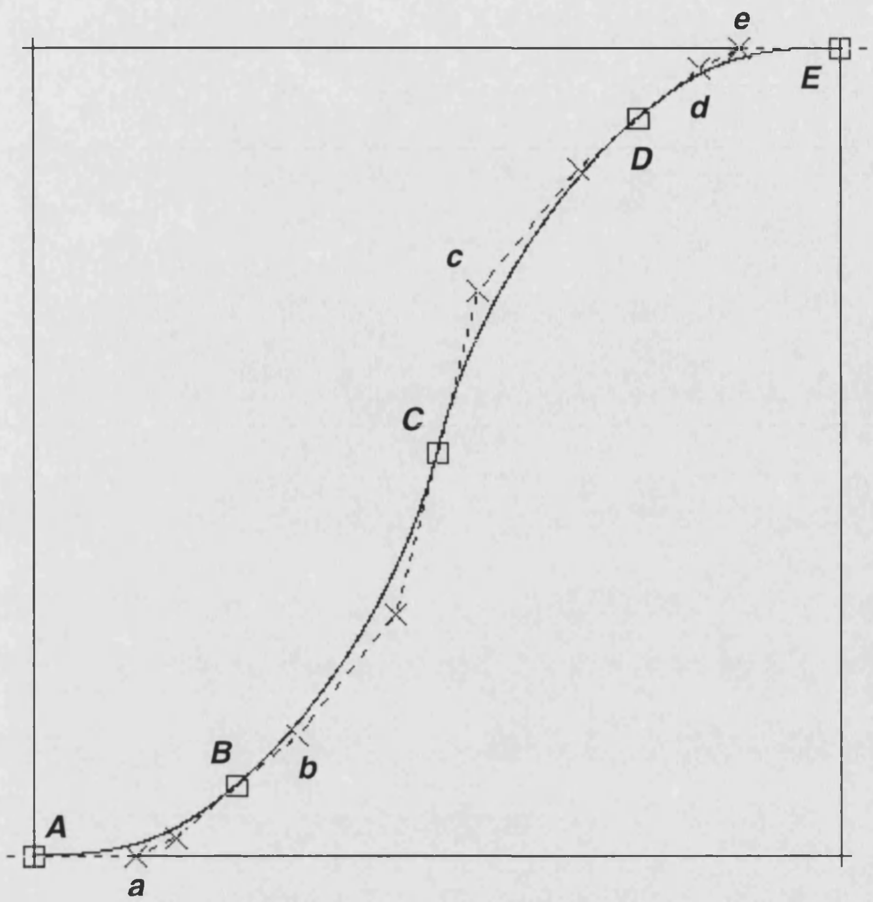


Figure 7.12 Slow-In Slow-Out Control Spline of Five Points

The main problems are now in how the adjustment can be carried out and to what extent, based on the emotional state values. Definition of what effects are required and how they can be implemented at various points in the time frame represented by the control spline are needed. The requirements fall into three basic categories. An increase or decrease in the rate of change of movement involving a change in main point position and associated control points, an adjustment of rate of change involving just control points and an extension of normal movement. The first two are similar in many respects with the adjustment of just control points being generally more subtle. There also needs to be some investigation into associated adjustments to the control curve to maintain the shape after initial adjustment. For example an adjustment of control point ***b*** affects the segment ***BC*** and also ***AB***. Thus there may need to be some adjustment of control point ***a*** to compensate and keep the overall shape of the control spline acceptable.

An increase or decrease in the gradient of the curve is an important adjustment to a control spline as it can be used effectively to express emotion. There are three main areas of the time frame where an gradient adjustment can be made using the main control points. The beginning of the movement, the middle and the end. These correspond with the main points ***B***, ***C*** and ***D***. The adjustment of points ***B*** and ***D*** are similar in effect and corresponding control point modification. An increase in the gradient at point ***B*** causes a resultant decrease in the gradient at point ***D***, and vice versa. This is because the increase or decrease adjustments are relative to other movement within the time frame.

An increase in gradient at points ***B*** and ***D*** can be seen in the earlier emotion examples of Disgust and Joy respectively, figures 7.5 and 7.7. As one control spline is an inversion of the other it is only necessary to examine one, the adjustments described can apply conversely to create the desired effect. A larger picture of the Joy basic emotion control spline example is shown in figure 7.13, with the main points marked ***A*** to ***E*** and corresponding control points ***a*** to ***e***.

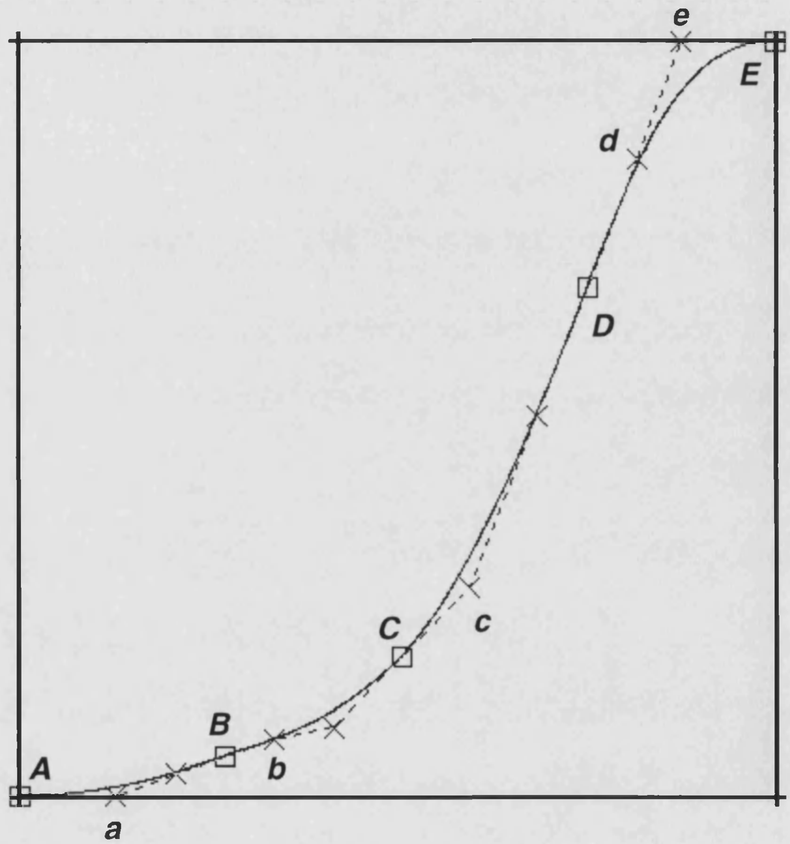


Figure 7.13 Basic Control Spline with Main Point Gradient Adjustment

The effect is created by a lowering of point ***C*** and to a lesser extent ***B***. This is complemented by a lowering of control point ***b*** and raising of control point ***d***. The adjustment of control point c is important to maintain the smooth line of the curve, in this case it has been moved down slightly to increase the gradient to its right and decrease that to its left. Adjustment of the gradient in the middle of the time frame is achieved largely by movement of the control point ***c*** upward or down and corresponding adjustment of the points ***B*** and ***D***. The resultant effect is to decrease the gradient at the start and end of the time frame. The extent of the effect on the start and end can be controlled by using the method described above to adjust the point ***C*** up or down.

The adjustment of control points to affect curve shape in conjunction with main point movement, or independently, is an important element. When main points are moved the surrounding control points usually need adjustment to maintain a smooth curve. The independent movement of control points can create subtle but important shape adjustment. It is important to remember than an adjustment of a control point has effects on both sides of the associated main point. An adjustment upward will generally increase the gradient in the segment after the main control point, but decrease the gradient on the other side.

The extension of normal movement is a useful tool in expression which is discussed in greater detail in the traditional animation technique section. The basic method involves adjustment of control points ***a*** or ***e*** to a position above or below the upper and lower movement boundary. This can cause the control spline to go outside these boundaries and hence result in extension of movement beyond that set by the key-frames.

7.5.2 Arithmetic Operations Applied to Control Splines

The definition of emotional state and its interaction with the posturing and animation process requires the mixing of basic emotion effects. The methods used in the posturing system is such that effects are broken down to simple joint angle operations and so can be integrated into the update of the figure easily. There is no need to calculate effects of one basic emotion and then mix them with another, as the calculations are encompassed in one equation. With the animation system the use of control splines allows for several possibilities. Given that you can define general rules with respect to the value of a particular basic emotion in the emotional state, and hence create a reasonable control spline for that basic emotion. How should you go about creation of control splines for mixed emotions?

Two approaches are examined here with respect to the current control spline definition. The first method is to ensure that the emotional interaction is such that the effects of each basic emotion on a defined curve could be used together on a single control spline. The second method applies the emotional interaction of each basic emotion to a defined curve, then adds the results together using weighting defined by the emotional state values.

The first method is to start with a basic control spline, such as a standard slow-in slow-out shape, and to manipulate this in accordance with the rules of the basic emotions defined in the current emotional state. This means that the adjustments made with respect to one basic emotion must be compatible with another. So for example, if the emotional state was that of joy and acceptance then the adjustment associated with joy would be applied followed by the adjustment associated with acceptance. The resultant control spline is that of the complex emotion.

The disadvantage of this approach is the possible restrictions placed on the emotional interaction. Any emotional adjustment implemented should be commutative. In the example used above it was stated that the adjustment of joy is applied followed by the adjustment of acceptance, but for this method to be effective the order should not matter. So if the adjustment of acceptance were applied first, followed by that of joy, then the result would be the same control spline. The advantages to this approach are that extreme emotional effects are controlled to a certain extent by the restrictions of commutative addition. When dealing with adjustment of control splines there needs to be an awareness of the effects of extreme emotional states. Care must also be taken to ensure emotional adjustment is compatible, that the adjustment of joy can interact sensibly with that of interest. It may be necessary to adjust weighting values to deal with this. For example the emotional effects of sadness may be satisfactory when applied by itself, but when mixed with that of fear the result may be such that the adjustment is overpowering. In this case the effects could be toned down appropriately to produce the required results.

The second method involves defining emotional interaction of basic emotions in a similar way. These are applied for each emotion to separate basic control splines, then the resulting control splines are added together, weighted dependant on the emotional state values. For example with a complex emotion of joy and acceptance the rules associated with each are applied to two basic splines of the same shape. The results are then combined according to the values of the basic emotions joy and acceptance in the emotional state.

In this method the addition of the splines must be commutative though the emotional interaction of the basic emotions need not be. This is the main advantage of the second method over the first, which means there is greater flexibility in emotional interaction. The disadvantage of this approach is that addition of control splines can produce undesirable results from extreme emotional states. This can be countered in a similar way to the first method by controlling the emotional interaction, or by adjustment of weights when adding control splines together. This a major difference of this method over the first, in that there are two areas in which adaptation can be made, the emotional interaction itself, and the addition process. This can be seen as an advantage or an unnecessary complication.

Given that the control splines to be added have the same number of main points and that they are spaced equally the method for addition is simplified. This is a further advantage of the main point restriction to five equally spaced points. To gain a reasonable approximation to the addition of two or more splines the positions of the main points are simply added together using weighting. The control points can also be added in a similar fashion giving a good approximation to the resulting spline. The control spline definition is re-computed from this information. This method applied to the emotional state model and use of complex emotions requires the incorporation of weights. These weights are based on the basic emotion values of the emotional state, which need to be normalised such that they total 1.0, before being applied as weighting to the addition process. This method is suitably commutative in accordance with the requirements and results in acceptable addition. Examples are given in the following section.

7.5.3 The Dynamic Emotional State

The emotional input to the animation process is defined as the dynamic emotional state, see figure 7.4, but how should this be handled? There is currently no definition of the emotional state in terms of rate of change. The examination of emotional effects on movement in section 7.3.1 looked at the emotions as constants rather than transitions. The system is currently working on the theory that transition change, the control spline definition, is affected to a larger degree by the final emotional state than the initial emotional state. Examination of emotions from a psychological point of view shows this is because the expressed physical change is often a result of internal physical and mental changes of state. Hence the outward physical response is after the mental change has occurred. The initial emotional state may affect the start of the motion, but the final emotional state should control the majority of the movement. This is an area of further development and study, discussed in Chapter 8.

7.5.4 General Discussion and Examples

Figure 7.14 illustrates some examples of the control spline combination techniques. Example A is the addition of a 5 point Straight control spline and a standard Slow-In Slow-Out control spline from figures 7.10 and 7.12 respectively. The result is to increase the tension of the movement because it is tending toward linear. This effect can be used on a variety of control splines. Example B is the addition of the 5 point Bell control spline and another standard Slow-In Slow-Out control spline from figures 7.10 and 7.12. The effect is the shifting of the 'bell' section of the curve to the right, and an adjustment of the final position to the mid-point. Example C is the combination of two emotional 5 point control splines, those of Surprise, figure 7.6, and Fear, figure 7.8. The result is a basic control spline for a frightened surprise movement. It retains some of the sharpness of movement of the Surprise control spline, while adding the linearity associated with increased tension in fear. Examples A to C are direct combinations with a weighting of 1:1, Example D illustrates the use of weighting in the combination process. It is an addition of the 5 point Fast-In Slow-Out and Slow-In Fast-Out curves from figure 7.10 with a weighting of 1:2. Initially the speed of the Fast-In is evident, but this is overcome by the greater weight of the second spline. These examples illustrate how the combination technique can work to produce acceptable control splines for use in a key frame animation system.

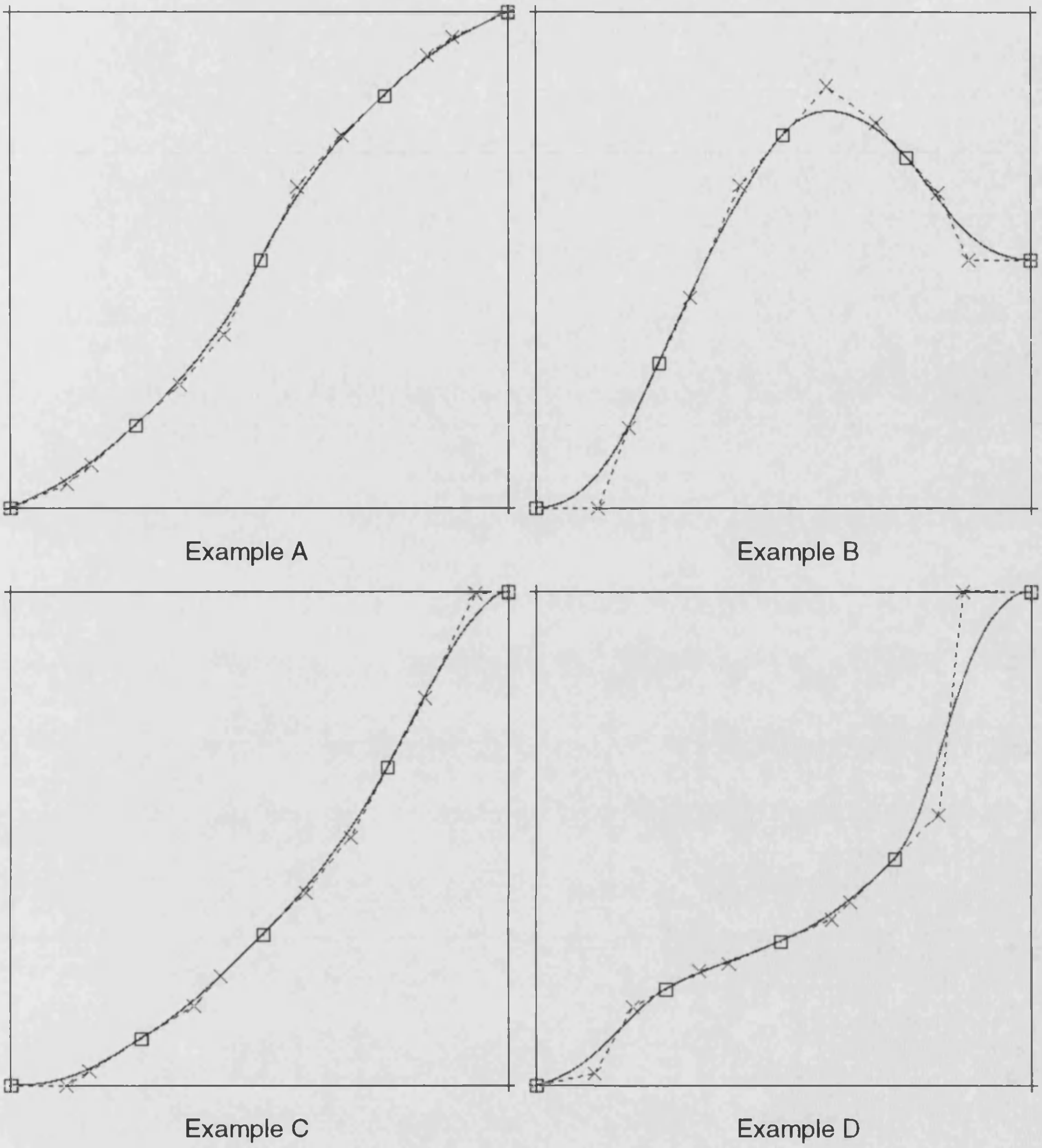


Figure 7.14 Examples of Control Spline Combination

7.6 Use of Traditional Animation Techniques in the Animation Process

Traditional animation techniques can play an important part in expression of emotion in the animation process. The flexibility of the animation definition allows the animator to include elements of exaggeration, anticipation and timing to the animation produced. The use of Inventor techniques to control Composition and Colour are also discussed in this section, though as with the posturing implementation these methods are theoretical and not implemented in the current system.

7.6.1 Exaggeration

Exaggeration in DEGAS can be achieved in several ways by using the posturing system to set exaggerated poses between which you then animate. It can also be achieved in conjunction with or solely within the animation system. The effect is created by careful adjustment of the control splines.

Exaggeration can be described as larger and quicker movements, so the change in the control spline should try to emulate these properties. To create larger movement the control spline can be defined so that it goes out of the normal spline area, above and below the movement limits. The definition of the curves requires that the main points be within the boundaries, but the control points which determine the shape of the curve between main points are allowed outside the boundaries. An example is shown in figure 7.15. Consider a normal slow-in slow-out control spline previously shown in figure 7.9, note that the curve always remains within the boundaries and that the associated movement increases from 0.0 to 1.0. The control spline shown here is the same basic curve with an adjustment in the control point associated with the point at (1.0, 1.0). This adjustment means that the curve now increases as before but at the end of the time frame it becomes greater than 1.0 before going back down to end at 1.0. The effect of this change is to make the associated movement exceed the final posture position before finally returning to it, thus exaggerating the overall motion. A side effect of this adjustment is that, as the overall movement is greater while the time frame remains constant, the motion is quicker than before. The third and fourth control points are also adjusted to maintain the smoothness of the curve. The second effect is also possible independently of the first. The average speed will be the same, as without the larger movement the distance moved is the same within the same time frame. However, by making the speed quicker in key areas, such as at the beginning, end or middle, the effect of exaggeration can still be achieved. This is shown in control spline B in figure 7.6, a basic surprise control spline. Here the movement rate is increased at the end of the motion resulting in a sharper finish to the movement.

Figure 7.16 shows these techniques used in practice. The sequence of four frames shows the arms moving beyond the final position in frame three, before returning to the end posture in frame four. The overall rate of transition of the arms is also increased as a consequence. The emotional connection to exaggeration in movement is associated with high emotional states where it is used to express clearly the feelings of the character. It can be used when the emotional state is high to re-enforce other emotional elements in posturing at key-frames and though the way the animation is carried out.

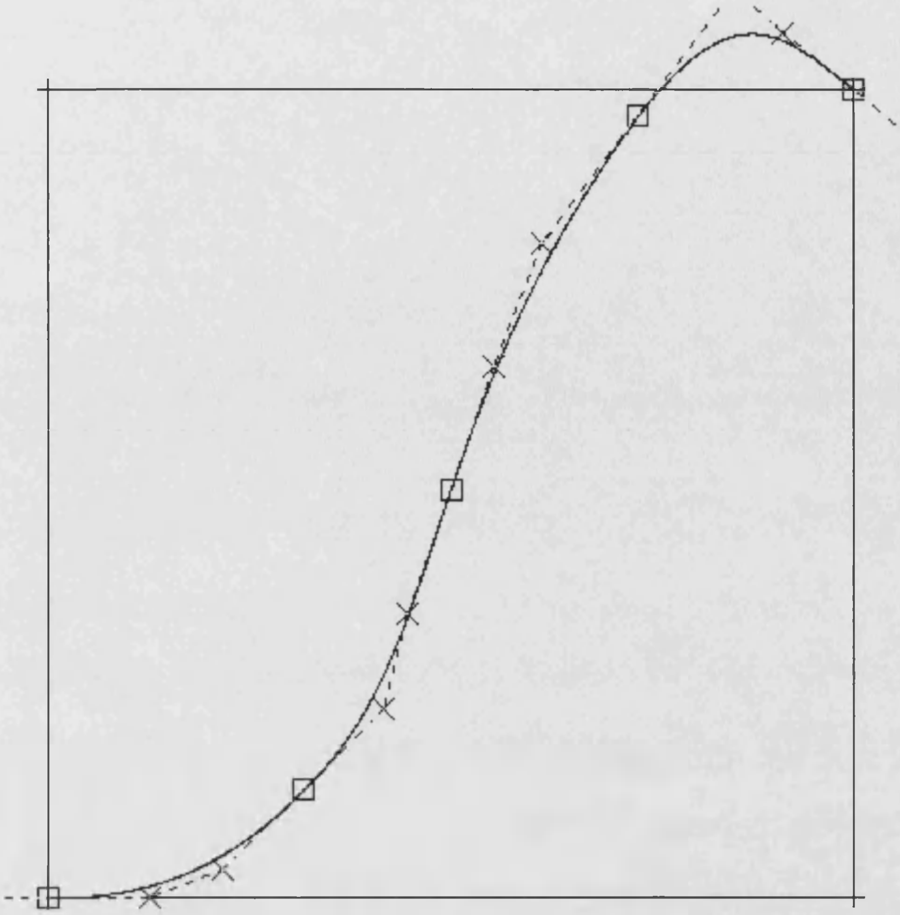


Figure 7.15 Sample Control Illustrating Exaggeration Techniques.

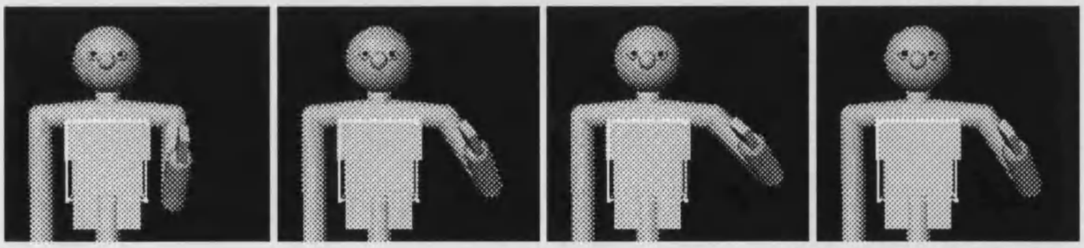


Figure 7.16 Sequence Demonstrating Exaggeration Methods Through the Animation System.

7.6.2 Anticipation

The use of Anticipation, the set-up or preparation of a movement, is possible in the animation system of DEGAS using similar techniques to that of exaggeration. In this case Anticipation refers to the emotion of the viewer rather than that of the animated figure, and this should not be confused with the emotional state of the figure. Anticipation involves preparing the viewer for a movement that is about to happen and subsequently increasing the impact of the movement. A simple example is the lifting of the back from a bending position. As preparation for the main movement of straightening the back the figure can initially lean a little forward to make the movement easier. This sort of anticipation can be simulated by careful adjustment of the control splines.

As with exaggeration the key to anticipation is making the movement go beyond the boundaries of the main points by adjusting the control points of the curve. With exaggeration this meant movement above the upper limit, with anticipation it is the lower limit which concerns us at the beginning of the movement. Figure 7.17 shows a control spline edited using this technique. The adjustment is similar to that of exaggeration, the control points near the beginning of the curve are adjusted so that the curve dips below the 0.0 line. This means the resulting motion at the joint angle this control spline is associated with will initially be away from the intended direction. This sets the anticipation, then the main movement takes over and the intended motion is carried out. This is shown in the sequence in figure 7.18. The main movement is that of raising the back, but from frame one to frame two the back is lowered. The final two frames show the main movement. It is also of note that the rate of movement of the main motion is increased because of the time used in implementing the anticipation. It is something which may need to be taken into account.

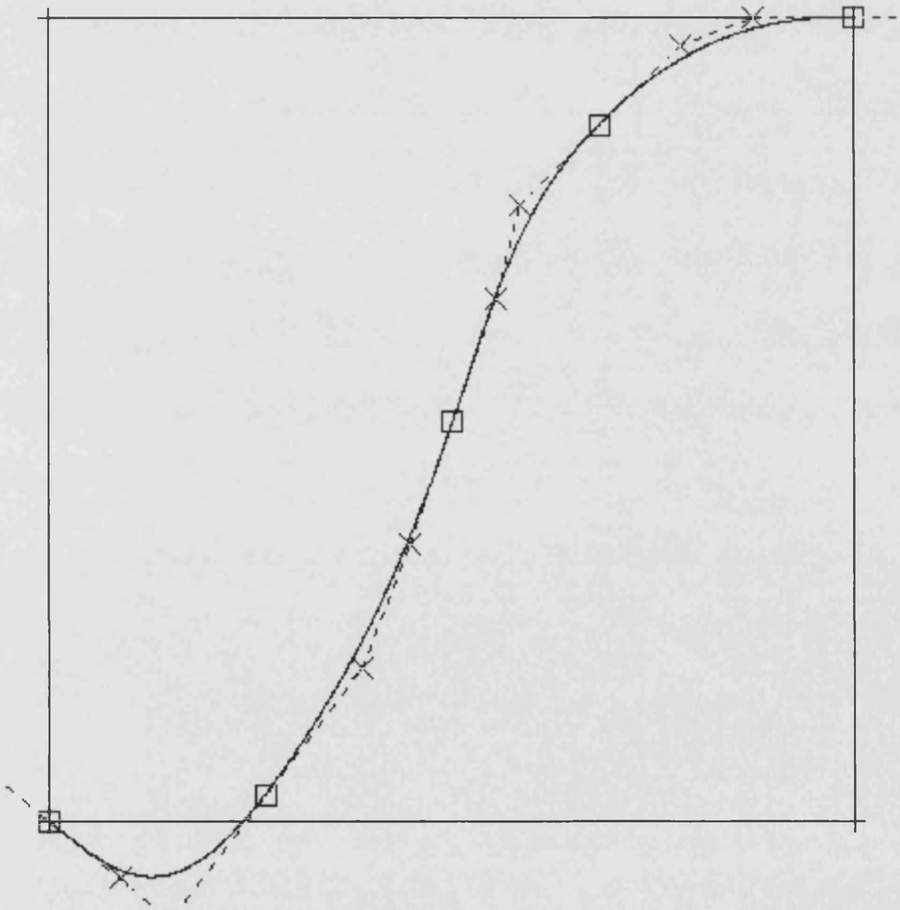


Figure 7.17 A Standard Slow-In Slow-Out Control Spline with Anticipation Methods Applied

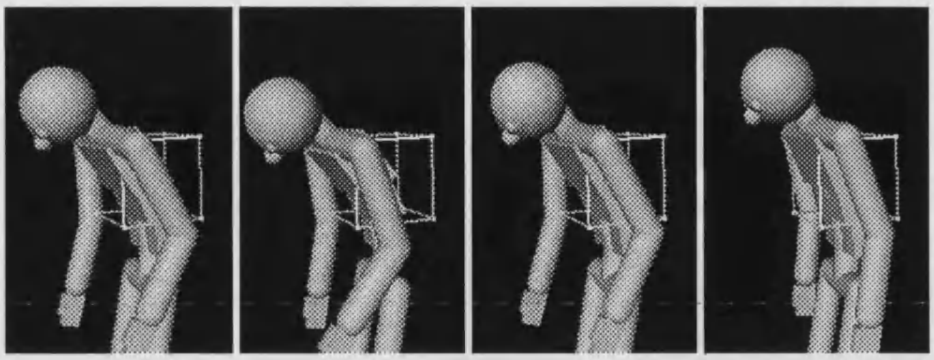


Figure 7.18 Sequence Demonstrating Anticipation Methods

As discussed previously anticipation here refers to the anticipation of the viewer and not that of the character being animated. There are useful connections with the emotional state of the figure however. It is always important to maintain emotional contact between the viewer and the character. If the viewer can relate to how the character feels then the emotional connections are re-enforced. The use of anticipation strengthens the link between viewer and character, by allowing the viewer to predict movement and by keeping their eye focused on the important aspects the animator wishes to express. The connection between viewer and character is an interesting point discussed in more detail in the section on further research.

7.6.3 Timing

Timing is an integral part of the animation process, managed through the definition of the control splines and setting of weighting factors. Apart from the main process of animating the figure from one posture to another there are other techniques involved with timing which can help the animator achieve their goals. These can be implemented by adjustment of the gradient of the control splines to make a motion faster or slower in specific parts of the basic animation. The use of timing techniques with respect to basic emotional interaction has been discussed in previous sections. There are further techniques which can enhance the emotional expression by combining the timing methods with exaggeration, resulting in over emphasised motion.

For example the basic emotion Surprise can be represented by a rapid and abrupt movement. By increasing the speed past that usually associated with the level of surprise defined, the animator can place greater emphasis on the motion. This technique can also be applied within the time frame by increasing the initial speed of movement and placing greater emphasis on the end posture which is subsequently held for a longer time.

7.6.4 Composition

Composition in relation to the animation system is closely linked with the composition issues discussed in the posturing implementation system. In this case we are dealing with transitions between composition to help create the desired effects, and support transitions in the emotional state of the character. Use of compositional techniques can be separated into two general areas, as an emphasis on a dramatic change in emotional state and to draw attention to a particular area to emphasise a specific emotion.

The first technique follows on from the posturing system composition discussion of using the camera angle to emphasise an emotion. For example using the relative status between the viewer and character to alter the view to look down or up at the figure. When applied to the animation aspects in the transition between two distinct emotions the camera angle and position can be moved between the two key-frames to emphasise the change. The motion of the camera and rate of transition between the two positions can be used to support the change in emotion. The rate of change must support the motion being carried out else the camera motion may confuse the viewer. Thus the movement of the camera should be linked to one of the control splines associated with an areas of the body representative of this change. For example consider a happy figure becoming sad by a drop in the shoulders and neck. The camera could emphasise this transition by moving the viewer lower and looking up at the figure's drooping head. This camera movement should be linked to the same control spline as that covering the main movement in the neck joints. This result is a re-enforcing connection between the camera motion and the main motion of the figures movement.

The second technique is also linked to the posturing compositional methods. This involves the concentration of the camera view on a particular body area to keep a particular point of interest and enhance the message given. For example where a motion is expressed mainly in the arms, such as excitement, the camera can follow the arms and make sure the viewer concentrates on the action. As with the first technique the result is a re-enforcing connection between camera motion and a particularly expressive motion of the character.

7.6.5 Colour

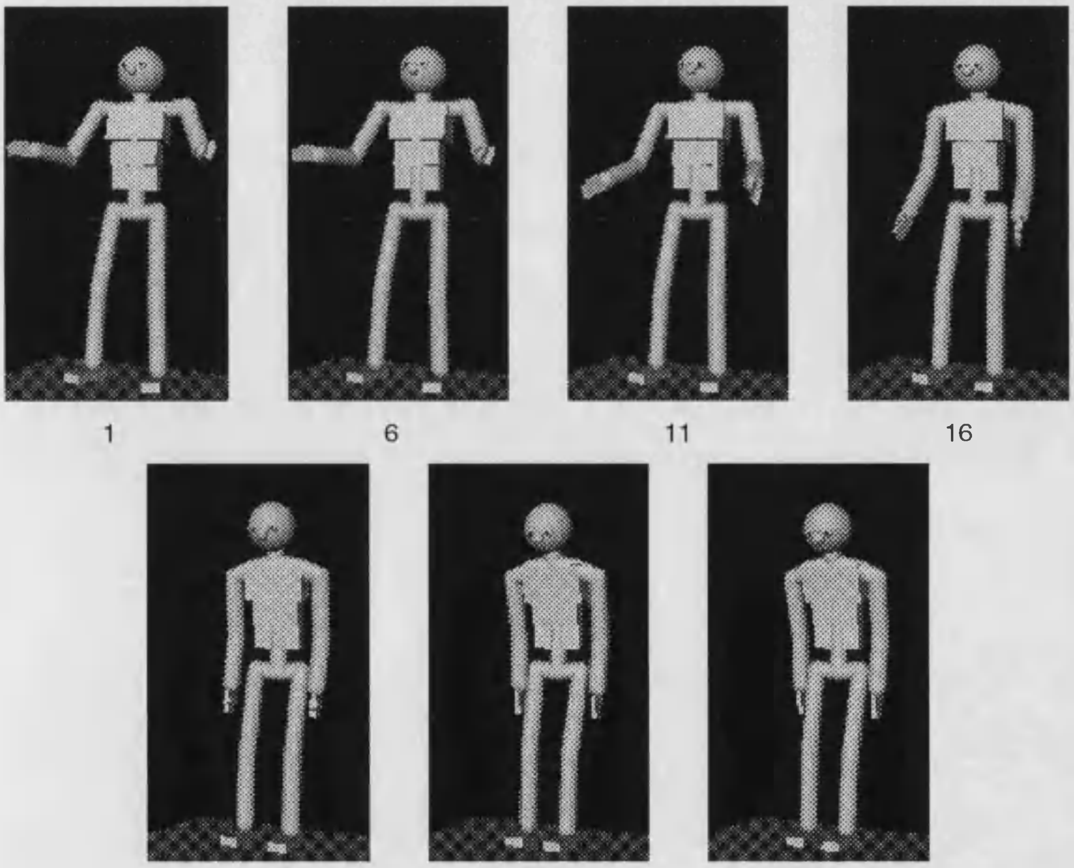
The use of colour in the animation process is similarly linked to the first compositional technique discussed previously. As with the composition technique the two colours used for the two key frames could be interpolated throughout the animation process. The rate of transition for the colours should again be linked to a control spline associated with the motion to create a connection between the colour change and movement. One point of interest which requires investigation is whether the transition can simply be applied to the RGB values individually. This would seem to be true, but investigation of the colours during the transition may be necessary.

7.7 Examples

7.7.1 Introduction

Examples of animation are difficult to display in a format such as this, but this section attempts to demonstrate animation possible with DEGAS. The examples will mainly be sequences of small images which demonstrate the main points of the system. The control splines used will be discussed but not given as many are previously shown examples. The control splines defined are more representative of the emotion they are translating to than those they are translation from. Where considered important, however, the initial emotion is taken into account. Thus for example if the transition is from Joy to Sadness then the control spline used is more representative of a sad movement.

7.7.2 Animation Sequences



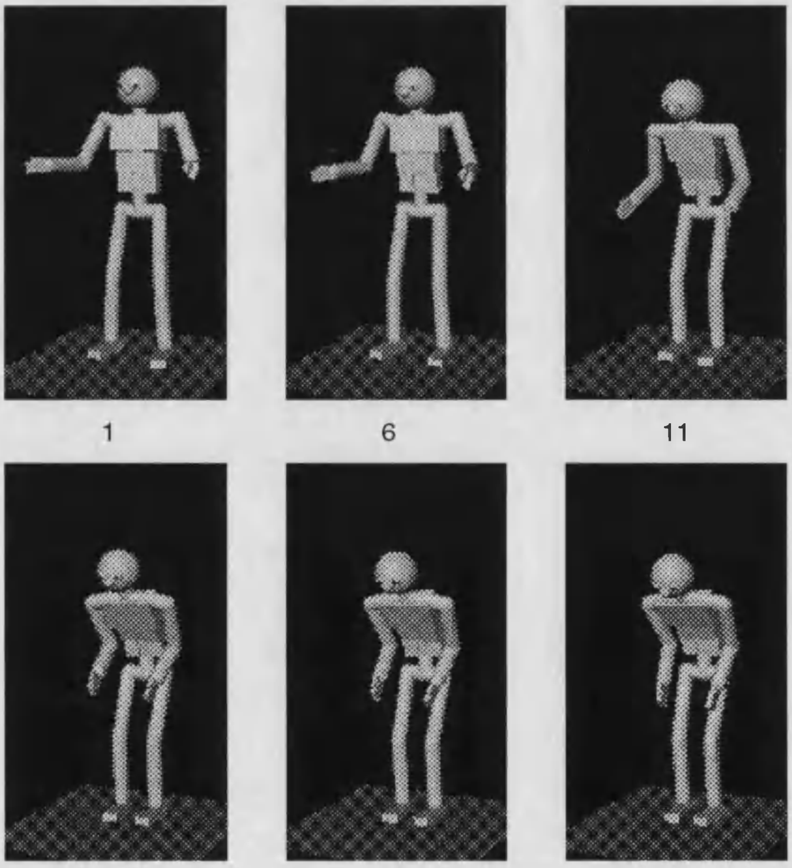
1 6 11 16

21 26 31

Figure 7.19 Animation Sequence (i)

The first sample animation, shown in figure 7.19, represents a 32 frame sequence. The transition is between the posture given in figure 6.34 example A, and the posture given in figure 6.35 example A. With the emotional state going from joy to sadness. The splines used for the transition were standard sadness splines adjusted slightly for quicker initial movement to reflect the initial joyful emotional state. The spline used for the arms and neck was set to reach the final position more quickly than other joints. The time factor was set at 1.5 reflecting the longer time associated with sad movement.

The second animation, shown in figure 7.20, is part of a 26 frame sequence. The transition is a three key-frame movement from figure 6.34 example A, through figure 6.36 example C, to figure 6.36 example B. With the emotional state going from joy, through anticipation and anger, to anticipation and fear. The splines used were direct combinations of a basic anticipation spline with a basic anger spline for the first translation, and in combination with a basic fear spline in the second translation. The time factor for the first transition was 0.75, and 0.5 for the second transition. This reflects the smaller movement of the second transition.



1 6 11

16 21 26

Figure 7.20 Animation Sequence (ii)

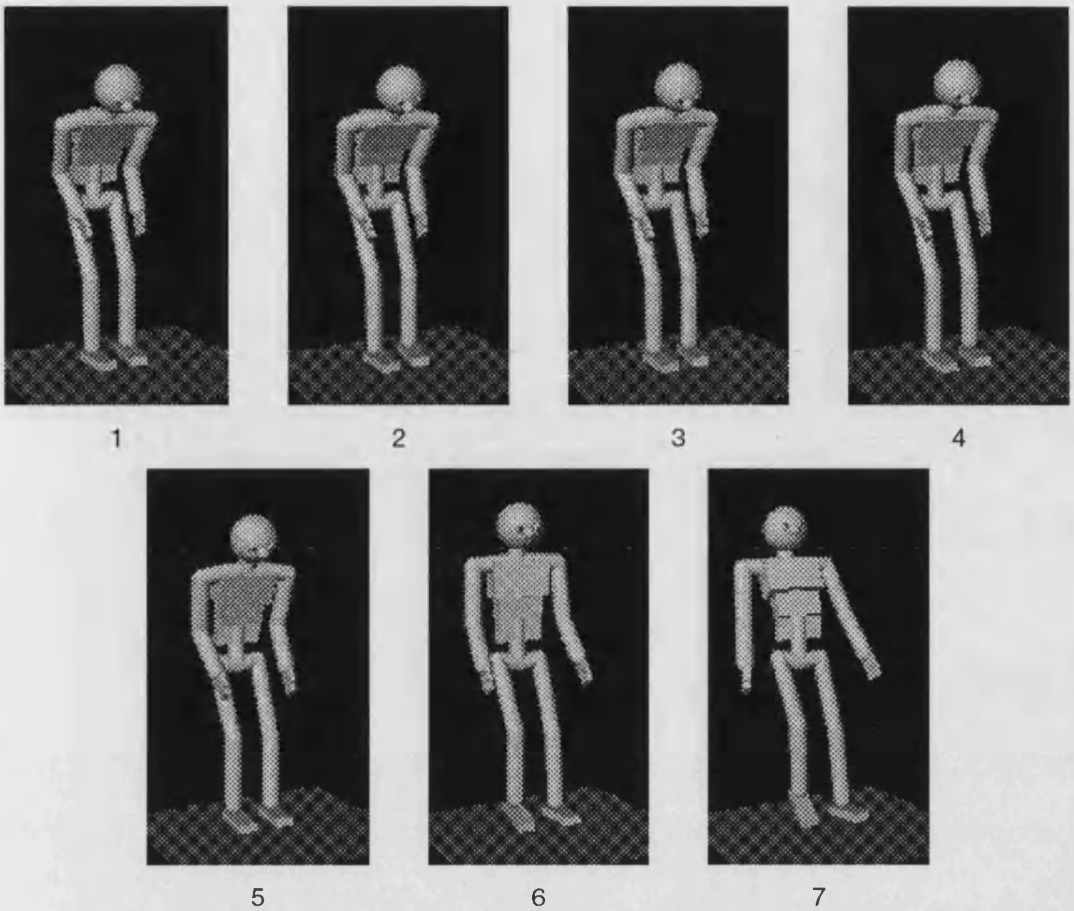


Figure 7.21 **Animation Sequence (iii)**

The third animation, shown in figure 7.21, represents all frames of a quick seven frame sequence. The postures used are example A from figure 6.36 and example A from figure 6.37. With the emotional state starting as anticipation with fear and finishing on surprise with joy. The spline used for all movement was a weighted combination of basic surprise and joy splines, with a weighting ratio of 2:1. This results in a slow initial movement with more rapid final motion. The time factor was set very low to give the surprise motion the appropriate speed.

The fourth and final animation is another three key-frame movement representing a sequence of 32 frames. The posture transition starts at example A from figure 6.38, goes through example B from figure 6.38 and finishes on example C from figure 6.39. Thus the emotional state starts as acceptance and joy, goes through acceptance, anger and fear and finishes on disgust and fear.

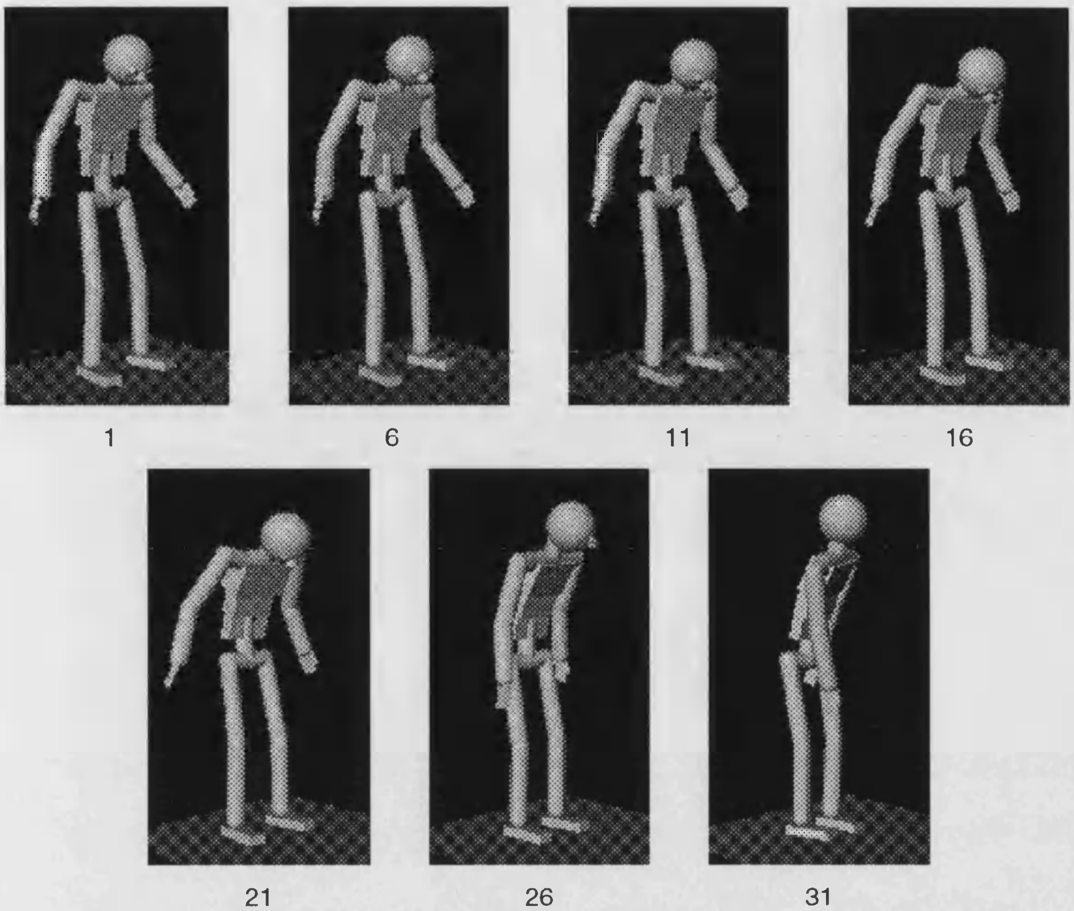


Figure 7.22 Animation Sequence (iv)

For the control splines of the first translation the basic curves for acceptance, anger and fear were used with a weighting ratio of 2:1:1, with a time factor of 1.0. In the second transition the basic curves of disgust and fear were combined equally, with a time factor of 0.5. This created a longer movement for the first translation, with a quicker movement associated with disgust for the second translation.

Chapter 8 Further Research

8.1 Introduction

The nature of the research and the system produced means there are many avenues for further development. The research touches on many areas and application possibilities so there are various directions in which subsequent work can be carried out. DEGAS has always been designed as a base for further development, therefore the potential for expansion and further application dependent definition is a major area of additional work. This section details these areas of expansion and study possible from the current position, and also work which would further enhance the posturing and animation systems.

Initial discussion will focus on areas of interest raised by the basis of the system, the psychological aspects and some of the less obvious concepts of the approach taken. There are many interesting issues connected with the relationship between the viewer and the animation, in terms of reinforcing what the animation is trying to achieve and in terms of the emotional connection between what the character is expressing and what the viewer feels. The possibilities for the expansion of DEGAS is also a large area, encompassing growth and development of the posturing and animation systems. This can be through extension of the emotional interaction and expansion of functionality.

8.2 General Research

The research carried out as a background to DEGAS and the main body of work touches on many areas. The scope of connected fields opens many possibilities to further research in those areas and subsequent development of the main area of emotional animation. Through definition and expansion, DEGAS can be used as a tool to further develop, test and explore some of the theories it is based upon, and also related areas.

8.2.1 Emotional Expression and Body Language

The psychological theories on which DEGAS is based are an on-going research area, where there is still room for development and further interpretation. One of the reasons for the requirement of definition in DEGAS was to allow for this development in these areas. This could be seen as a weakness in DEGAS as it can make the system too general, but it can also be one of its greatest strengths. By practically implementing the ideas of the psychological research DEGAS may test and further develop those theories.

Further to the expansion of theories used in DEGAS it is also feasible to explore related psychological areas of study. The theories of body language can be defined, but the reaction of the viewer cannot always be predicted because of the added factor of the viewers interpretation of what they are shown. A movement which means one thing to a person may mean something entirely different to another. By using an animation system to test these differences it is possible to examine them in more detail. The animation used can be manipulated and subtlety changed as a consequence of a person's reaction, thus making this method highly adaptable to a changing situation. Examination of a person's understanding, why they get certain messages from a movement, and where the messages are coming from, is an important area of study. This type of application for DEGAS can also help in further development of the system itself, by gaining greater understanding of the theories on which it is based.

8.2.2 Perception

Perception of movement by a viewer could be an important key to further development of the system and future animation systems. Techniques from traditional animation, such as anticipation and timing, are already used to direct the viewer in what messages they receive as an animation is carried out. This could be further developed with particular attention to emotion.

It has been shown that emotion is felt with greater intensity in particular areas of the body. With this in mind it may be helpful in expressing a particular emotion to direct the viewer to these areas, to reinforce the emotion. This can also detract from deficiencies present in the animation. It is important not to distract the viewer from the main point of an animation, so that the message is not confused.

As with the general emotional expression and body language development, perception techniques could be investigated using DEGAS. By producing differing animation on a basic motion, and testing the responses of viewers, it can be possible to explore these areas.

8.2.3 The Emotional Model

The emotional model used by DEGAS was chosen for its simplicity of definition while allowing for a complex set of emotions to be used. There are applications which would benefit from a change in the emotional model structure to suit requirements.

If the system was further developed as a strict animation system it may be that animators would want a more basic control over the emotional state of the figure. This could involve a reduction and change in the number of basic emotions to a more commonly used set. While reducing the ambiguity of the basic set of emotions, this would also reduce the complexity of emotions possible. This could be balanced by greater input from the animator, who can define the more subtle effects after the basic set up of the posture or animation.

If the development of the system was more toward a psychological research tool then the current emotional model may be too simple for these purposes. The model could be extended in three key areas. The extension of the basic set of emotions, the implementation of masked emotional expression and the addition of tension modelling. The addition of tension to the system is discussed in the relevant posturing and animation expansion sections.

The current emotional model could be extended by adding or replacing base emotions to further define the meaning and possibilities. There are several other models which contain ten or more basic emotions, and the number and definition could be tailored to suit the requirements of the application. Masked emotions could be implemented by storing two emotional states, the emotion experienced and emotion expressed. The emotion being experienced by the figure is filtered to produce the emotion expressed dependent on the situation and what the character wants to express. A character putting on a brave face despite feeling sad is a good example of masked emotion. The expressed emotion of the character is not simply what they want to express as it is very difficult to disguise true feelings. There has been some work in this area with facial animation [26] and behaviour studies [28, 34], though no specific work has been done in terms of body language in character animation. The concepts of masked emotions fit well with the DEGAS approach to emotional expression. If a person is hiding their feelings then they might try and perform obvious emotional body language to cover their true feeling. This could be achieved in DEGAS by use of mixed emotion techniques and applying different emotional states to different parts of the body. For example if someone did not like another person, but was forced through circumstance to act with acceptance toward them there would be signs of this underlying feeling. If they greeted them with a hug their arms may well come forward expressing acceptance, but the rest of their body may express disgust by being as distant as possible. Here varying degrees of acceptance and disgust could be applied to the appropriate areas of the body. The difficulty of masked emotions is that while the internal processes are understood, the external expression is not so well defined. The use of an animation system could help further study in this area, and explain some of the links between what we feel and what we express.

8.2.4 The Connections Between Viewer and the Animated Figure

In the Psychological Issues and Animation Implementation sections the connection between the viewer and the animated figure was mentioned briefly as an interesting area for further study. There exists some useful connections in terms of the emotion expressed by the figure and the effect this has on the viewer which could be used effectively in an emotionally based animation system. The techniques would be similar to those used by actors and actresses to manipulate the way the viewer feels and interacts with what they are shown. This could possibly then be used in the training of actors and actresses.

8.3 Posturing System Expansion

The Posturing system of DEGAS was designed as an expandable basis for the research. There are five main areas of further development. The high level control system, which allows for the addition and testing of new controls, the associated emotional interaction of the high level control system, the use of traditional animation techniques, modelling issues and general system development.

8.3.1 High Level Control Function Expansion

The list of high level control functions implemented in DEGAS was intended as a test bed for the techniques and is by no means exhaustive. The development of new basic high level control functions can be achieved by using the global user defined functions and the DEGAS information file. Once developed the structure of the DEGAS program code allows for full implementation to be quickly and simply achieved. Development of more complex high level control functions would require more testing, but the implementation should be similarly quick.

The current list of high level controls gives basic functionality and manipulation of the figure. Expansion would be on refinement of the basic controls to more goal directed or specific tasks. Specific posturing of body parts such as hands and feet by positional definition is a complex but useful area. The implementation of interaction between body parts, such as the hands and the head, would also be a useful addition to the high level controls.

Further definition of high level control functions already implemented is also a possible area of development. The goal directed control functions such as Turn Toward, Look At and Point At could be further developed to allow more definition by the user of how they are carried out. There are also know problems with the goal directed methods which need to be addressed.

Posture specific controls are also a useful possibility. The set of controls could adapt to the overall defined posture of the figure, such as sat down or lying. The posturing elements in these situations can vary greatly from the standard set, which are more useful for a standing figure. This can be used to reflect the changing relationships between the limbs of the body in various postures. When lying or sitting the role of the legs is no longer as main support for the rest of the body for example. When the figure is in a non-standing position the model file may need restructuring to allow for the movement of the root of the figure. This has been discussed in section 4.2. Restructure of the figure is acceptable as long as the required named nodes are still present.

8.3.2 Development of Emotional Interaction

The emotional interaction in the posturing system through high level control functions is defined so as to be simple to use. Is there a need for a more complex connection between the emotional state and how the control function values are interpreted? The user input to the interaction needs to be simple, but the underlying calculation could become more complex. The necessity for this sort of development is not certain however. While a more complex system would allow for greater interpretation of the psychological issues a balance is needed to cope with the imprecise psychological theories on which the system is based. The interaction must allow for the developing theories in these areas.

A possible extension to the emotional interaction is to incorporate an emotional history, a list of previous emotional states from key-frames felt by the figure being animated. There are emotional theories which suggest that the emotion we feel due to some stimulus is directly affected by our current emotional state and recent previous emotional states [40]. It would be interesting to test these theories within the context of DEGAS, as an examination of the theory itself and the emotional interaction used by the posturing system.

Much of the emotional interaction literature covering the psychological theories mentions tension and changes in tension relating to emotional expression. It could therefore be advantageous to look more closely at how tension is represented in the system as it stands, and whether some user definition of tension should be implemented. Tension is currently implied by the emotional state values, and taken into account in the emotional interaction process, though no value of tension is assigned or calculated specifically. This allows for interaction to be based more on the connection between emotional state values and the body area affected. This technique means the user has indirect control over the tension of the figure through setting of the emotional state values and the definition of emotional interaction in the DEGAS information file. If tension was given a value, as a combination of user definition and implication from the emotional state, then the possibilities for emotional expression could be expanded. For example a high emotional state of joy will currently imply a high tension in the figure using the current associated DEGAS file. If the animator wanted a highly contented emotional state it would imply that the figure should be happy but not necessarily tense. Under the current system a separate DEGAS information file may need to be defined to allow for this, as it is a change in how the emotional interaction occurs.

8.3.3 Development of Traditional Animation Techniques

In the Posturing Implementation chapter the use of traditional animation techniques in DEGAS were discussed in the context of how they could be achieved using the system. These areas could be further developed by the automatic implementation of the techniques, rather than the animator working through the system. It would be useful if the animator could simply specify a level of exaggeration to be applied to a posture, and let the system apply it. With secondary action the definition is already possible through high level control function definition. However, this can be restrictive on which areas can be affected by specific control function. This could be addressed by allowing the user defined functions to be linked to another named control function. Thus cross body connections would be possible.

The use of colour and composition was discussed with respect to DEGAS, but the implementation of these techniques requires further development of the system. This would involve the camera position and colour being part of a posture definition, and the addition of controls to manipulate the values suitably. Composition techniques such as the focus of attention being placed on a particular object are possible through the Examiner Viewer. This could be further complemented with more specific emotion and balanced targeted controls.

8.3.4 Modelling Issues

The current DEGAS figure, while sufficient for the purposes of this research, is limited to 54 joint angles which can be restrictive in some situations. This could be extended by adding greater numbers of joint angles to the hands and feet, and facial area. These regions, because of their complexity, were not included in the original work. They could now be added by applying some of the techniques learned from this research.

The definition of the figure is based around a basic human design, while it has been possible to demonstrate the adaptive nature of this approach through the creation of the duck model, it would be advantageous to have a more generally defined approach. This would allow for the creation and animation of far more diverse models in DEGAS. Looking at the high level control functions it is possible to define actions being carried out on particular areas of the body, or objects, rather than defining specific named joint angles. For example consider a four legged animal. The high level control function Point At (Left Arm) would not apply sensibly to it as it adjusts the arm of the figure. If the function were defined as Point At (Pointer One) instead, and in use it operated on an object defined as Pointer One then it could be applied to both models. For the human Pointer One would be defined as the left arm of the figure, for the four legged animal Pointer One could be defined as the head and neck. This would mean that the four legged animal could still use the high level control function sensibly and point at things with its head instead of a limb. A general breakdown of the figure into components such as this, based on common animation techniques, would help in this respect.

8.3.5 General Development

There are three main areas for further general development in the posturing system. The provision of more user friendly control over emotional interaction and high level controls, the implementation of collision detection and the extension of DEGAS information file usage.

In DEGAS the user definition of high level control functions and their emotional interaction can be a difficult task. This could be improved greatly with an a user friendly interface for interaction with DEGAS information files. Ideally this should provide functionality to edit the information in a clear and concise manner from within DEGAS. The editing of the DEGAS information file should also show immediate results with the figure updating as the data is changed. This would allow the animator to create a DEGAS information file to suit the character they are animating quickly and easily.

Collision detection is currently not implemented in the posturing or animation system of DEGAS. It is left to the animator to ensure that no unacceptable movements or posturing occurs. This is helped to a certain extent by the constraints structure, which can restrict movement of joints to avoid some collision, but there are situations where further collision detection would be advantageous. This can be achieved by a combination of techniques, the Open Inventor functionality and the extended use of the DEGAS information file. Open Inventor provides techniques to find bounding boxes of objects in the scene graph in global co-ordinates, that is the definition of a basic box which contains the object. For example through this method the bounding box of the lower arm could be calculated. The bounding boxes of several objects may therefore be computed and compared for intersection. The reduction of scene graph objects to simple boxes reduces the computation for intersect with a trade off in accuracy. This provides the functionality for determining collisions but it is not all that needs to be calculated. Some bounding boxes, such as that of the upper and lower arm, need to be able to collide for the joints to be usable. In other cases the animator may wish that collision should be possible to a certain extent. The human body is not a rigid shape, deformations and changes in form can occur. It is therefore necessary to extend the functionality of the DEGAS file to give information on which collisions should be checked, and to what extent.

Collision detection information is one use of an extended DEGAS information file, but there are other possibilities. These relate to extended functionality of high level control functions, issues regarding the use of non-human figures and storage of further figure related data. The extensions to the number of high level control functions and further definition of current techniques may require extended functionality in the DEGAS information file. For example the implementation of passing back of movements required a connection structure, which was subsequently added to the DEGAS file. The extended use of non-human figures discussed previously in section 4.2, requires more functionality in the DEGAS file also. The information file is a part of DEGAS which allows for this sort of extension of ideas and requirements.

8.4 Animation System Expansion

As the animation system is not as well developed as the posturing system there is ample room for expansion in this area. These can be classified into four main areas, the development of the animation process, the associated emotional interaction, the use of traditional animation techniques and general system development.

8.4.1 Development of the Animation Process

There are three main areas of development in the animation process. Extending the number of postures which define the animation, allowances for specific animation methods, such as cyclic animation, and extensions to the control spline definition.

The animation process currently allows for the animation between two or three postures. This could be developed to allow for more postures and specific techniques, such as cyclic animation. The provision for the use of more than three postures extends the technical advantages of three postures over two. It allows the animator to control the transition joins between postures of a longer sequence more readily, and check the animation is satisfactory. This is useful when an long animation is being constructed with a large number of short animation. There are other techniques which are possible within control spline definition which could also help in this area, discussed later in this section.

The provision for specific animation techniques, such as cyclic animation, would also make the process more usable. To create a cyclic animation with the current system requires the joining of an animation sequence to a copy of itself several times. With this method it is difficult to judge the effect of the repetition until the sequence has been put together. It is also difficult to apply translation adjustment which is required by a walking or running motion. The character would appear to be running on the spot.

The definition of the control splines allows for a large degree of further development in its use and implementation. A practical addition would be the ability to load and save spline sets, not implemented in the current system. This would allow for the further development of saving and loading of defined animation, consisting of a number of postures, the associated spline sets and the model file to apply the animation to.

The functionality of the control splines could be extended to allow for more accurate definition of control points and various degrees of continuity. The current method of control point definition is a workable, visual process, but accuracy in definition is not catered for. Consider an animation being created which involves joining several short animation together. Unless a method of more than three postures is implemented, as discussed previously, then the joins of the animation may have continuity problems with regard to the control splines used. It would be helpful if the control points of the final point on the control spline of the first animation step were in accordance with the control points of the first point on the control spline of the next animation step. So that C_1 or G_1 continuity can be maintained across animation step joins. This could also be coupled with more accurate placement of main points on the control spline. Allowing the user to specify the point in terms of values rather than with the mouse. This would mean that the animator would be able to accurately specify posture transitions.

Varying the degree of continuity applied to a particular point on a control spline would help allow for greater variety of movement within a key-frame to key-frame transition. Currently C_1 continuity is forced, such that if a control point is adjusted on one side of a main point, then the related control point on the other side is also adjusted. This means that the transitions between key-frames are smooth and do not allow for sharp changes of movement within the transition.

The manipulation of control splines through control point and main point adjustment provides a certain level of functionality. This could be improved by examining further techniques for spline manipulation such as sub-division and increasing the order of spline segments.

8.4.2 Development of Emotional Interaction

The emotional interaction in the animation system has been mainly investigation of possibilities put forward by the general approach taken. As such further development in this area would be in putting into practice, and extending through implementation, some of the methods discussed. There are also several further ways to develop the emotional interaction as a result of development in the posturing system.

As further development of the posturing system the idea of tension and implied tension were put forward. This can extend to the animation system by considering the dynamic emotional state. The effect of tension is more actively expressed through movement hence this would be an important addition to the animation process. The tension of the figure at key points during the animation could be calculated based on an interpolated emotional state and tension values defined by the user for the two postures. In a similar way to proposed emotional interaction the key points could be defined by the five points of the generated control spline.

During emotional interaction the rate of change of emotional state is assumed to be a rapid change to the final emotional state. With control over the rate of change being passed indirectly to the animator through their manual adjustment of control splines and posture definition. This could be altered to allow for the rate of change to be defined in a similar way to postural change through control spline association. The possibilities become more complex if you then allow separate control splines to be defined for each basic emotion of the emotional state. This further extension may be too complex for appropriate use by the animator however. The transition time frame is a short period and hence the single control spline should be sufficient for most applications.

Another idea put forward in the posturing development section is that of an emotional history affecting how new emotional states should be interpreted. This again extends further to the animation system where the dynamic emotional state and its affect can be determined using a history of past emotional states.

8.4.3 Development of Traditional Animation Techniques

The discussion of traditional animation techniques in the Animation Implementation section detailed several techniques for the use of exaggeration and anticipation in the animation system. The techniques were all user implemented through the functionality of the system rather than implemented by the system itself. By manipulating the control splines in a similar way to the emotional interaction the system could achieve the effects of these techniques automatically. This frees the user from manual manipulation of the control spline and allows implementation through a single value.

In the case of anticipation the animation system allows the process to be taken a step further when three key-frames are used. The described process involves the set up of anticipation movements based on the transition between two frames. When three frames are used there is the possibility of extending this process to the transition from second to third frames as well. Instead of implementing anticipation based on the first transition movement, the anticipation can be applied to a greater degree based on the movement of the second transition. For example consider the movement of a figure from a standing position to that of jumping, going through a crouched position. Anticipation as described previously applied to the first transition, from standing to crouching, would result in the figure moving up slightly in anticipation of the downward movement. When looking at the overall movement the more dominating action is the upward motion of the second transition. It is this which the anticipation should be in relation to. Hence a slight movement downward then up, before the main motion down to the crouch position, would be appropriate. This is subtle simulation of the first transition, rather than an opposing motion in relation to it.

8.4.4 General Development

The general development of the animation system requires implementation in three main areas. The provision for constraints, collision detection and the implications of extended use of non-human models.

Constraints implemented in the posturing system are not checked in the animation system. Generally this is not a problem as the transition is from one constraint checked posture to another, however problems can occur if the control spline definitions exceed the boundaries. This can be used when implementing exaggeration and anticipation, where movement carried out goes beyond the defined key-frames to achieve the desired effect. Implementation of constraints in the animation system could be achieved in two ways. Checks can be made as the animation is carried out, and movement limited accordingly. Alternatively the check can be carried out on the control spline before the animation is carried out. This would enable the animator to be warned of any problems and make adjustments where necessary. The second method is preferable as the first could produce some awkward movement as the intended motion is constrained. The second technique allows the animator to adjust the control splines so that no constraints are exceeded while keeping the animation smooth.

Collision detection in the animation system is more complex to implement. Without greatly altering the defined animation the most collisions could not be automatically corrected or allowed for. In an emotionally based system this is especially important as the defined animation expresses a particular emotion. If it is changed it can effect the message and body language significantly. An alternative is to allow the animator to check whether collision occurs during the animation. If there are problems the animator may then decide whether the collision is acceptable or if a change in the definition of the animation is required.

The use of non-human figures in the animation system has less bearing than in the posturing system. However it does present the idea of using high level control function values to define an animation rather than the explicit joint values. In the posturing system the definition of high level control functions through the DEGAS information file allows for the use defined postures with different models. That is, that a posture defined and saved for a human figure could be used for the duck figure, and interpreted in a sensible way providing there was not extensive use of the low level controls. This could be extended to the animation where currently it is stored as the explicit joint values for each defined frame. If instead the control splines were applied to the high level control values as well as low level controls, and these values were spooled to a file instead of the explicit joint values. Then the resulting spooled animation could be applied to both human and non-human models.

Chapter 9 Conclusions

9.1 Introduction

This chapter focuses on a critical appraisal of the research carried out and the results achieved through DEGAS. Discussion will be of the goals and targets set originally, how these have evolved with the system, and where they have been met. Each section of DEGAS, the overall system in the context of emotional figure animation, the posturing system and the animation system will be critically examined.

9.2 Emotional Figure Animation and the Design of DEGAS

Research into figure animation has provided useful and workable methods for the creation of human movement in computer graphics. The methods using kinematics and dynamics have been accepted into the commercial world and are used in popular animation packages. The results of these techniques were fluid and impressive, but often unnatural looking and without human characteristics. My initial research objectives were to investigate this problem, specifically from an emotional angle, to see how difficulties could be addressed.

9.2.1 The Design of DEGAS

In designing an animation system around the ideas of emotional figure movement great care was taken to assess the importance of psychological research and understanding. The current methods of figure animation were studied to examine where the main difficulties were and how they might be addressed.

The most important aspect of the psychological theories was the variation and diversity in some areas of research. Where mathematics and to a certain extent physics are based on definite scientific foundations the psychological theories were imprecise and uncertain. This greatly affected how DEGAS was designed in order to grow with, and possibly shape, further research. The trend in computer animation was toward automation, generation by the computer of posturing and motion with limited human input. When considering simulation and basic animation this approach is adequate. When applied to the concept of emotional animation and the related psychology it appears inappropriate, because of a lack of definition and understanding in these areas. Thus a decision was made to take a step back from the current theories and look again at the problem. To use psychology of emotion in an animation system it is necessary to translate the verbal form of body language and movement theory to a more defined numeric form. The difficulty associated with this change meant DEGAS was designed to be adaptable to attempt to solve the problem, and be used as a tool of further investigation where solutions could not be found.

A significant element associated with the problem of natural figure animation is that when watching computer created animation it is obvious that it is not real. The difference becomes more apparent when compared with motion captured movement. Even with motion capture the animation generated can be recognised as different to natural movement due to the restrictions of current equipment. The application of motion capture data is also restricted such that there is a need for more versatile animation. Human input by an animator is an aspect of great interest, especially when considering that it was an element missing or neglected in other animation methods. It was decided to investigate the human element making the animator a significant part of the animation process. An significant factor in emotional figure movement is the importance of key postures during an animation. Hence in keeping with the importance of the animator, DEGAS was designed as a key-frame animation system. To facilitate the input of the animator the system was designed to allow ease of use with overall control where needed. The realisation of the importance of human input was a significant step, but there is a difference between knowing an animation looks unnatural and knowing why. The investigation and implementation of traditional animation and artistic techniques was used to counter this problem.

The approach taken in the design of DEGAS required a definition of emotional state to be associated with the figure being animated. Here extensive investigation of accepted psychological theory was undertaken to find a model suitable for this purpose. The criteria of ease of understanding and flexibility were met by a simulation based on the Plutchik emotional model. By defining the emotional state in terms of a basic set of emotions it allows for easy definition for normal use, and more complex definition where required. The fact that the basic emotions were defined in pairs also reduced ambiguity of definition.

To a large extent I feel DEGAS has approached the original design concepts intended. Areas where I feel the main improvement in design could be made are in user interaction and definition. Due to time constraints I have not been able to implement some areas with the ease of use found in professional animation packages. DEGAS aims to bring an element of creativity and human input to a process where most research concentrates on automation and simulation.

9.3 The Posturing System

The posturing system is the first section of the two part animation process. Reflecting the importance of main postures in an animation sequence the posturing process of a key-frame animation system plays an significant part.

9.3.1 As A Whole

The main requirements of the posturing system were ease of use and the implementation of definable emotional interaction. The main component which allowed for this was the design and use of hierarchical control of figure manipulation. Through this, general posturing could be made by defining the overall pose, which could then be refined through low level control. The design of the high level control system made the posturing process quicker, and also allowed for greater user interaction through definition in the DEGAS information file.

The definition of high level control functions also allowed for diversity in the approach to posturing through the implementation of traditional animation techniques. These techniques are useful in addressing difficulties associated with emotional theories by reinforcing the emotional message of a posture. The techniques have been used for many years in traditional 2D animation and some methods are particularly appropriate to emotional animation.

Figure design is an area where time restrictions have meant it was not developed to the original vision. The intention to use the same system to animate any suitably designed figure using the same methods has not been realised. The use of a duck figure has been implemented, but the techniques used are highly restrictive in nature. The work in this area has been limited to examination of general techniques and their application to more general figures.

The general results achieved show that the system is flexible and adaptable, though user interaction is often cumbersome. It provides a suitable test bed for further investigation of general and emotionally specific animation techniques. The definition and number of high level control function was chosen as an adequate set for the testing of the theories on which the system is based. The design of the posturing update and implementation was set so as to allow for the future addition and testing of further high level controls.

9.3.2 Emotional Interaction

Emotional interaction through high level controls is the main emotional involvement in the posturing process. The definition of interaction and its use is a key factor in the success of the system as a whole: if the key-frames are wrong then the animation will also be wrong. There are many issues involved, such as interpretation of psychological theories and perception, which made this a difficult task. The design concepts behind emotional interaction are built to combat these problems and allow for further investigation of their nature.

The main definition of emotional interaction in basic high level controls has been kept at a simple level to maintain the importance of animator involvement. The ability to adapt high level controls and their emotional interaction through use of DEGAS information files has allowed for this. There was also the requirement that mixing of emotional interaction defined in terms of basic emotions should be possible based on the emotional state definition. This was allowed for in the design of emotional interaction.

Definition of how emotional interaction should affect the posturing of the figure was examined on two levels, in general terms based on the basic emotions of the emotional state, and further application of these emotional theories to specific high level controls. There was a large degree of generality which could be deduced dependent on the basic emotion, the type of joints to which the high level control applied and the effect on those joints. This suggests a more general definition of emotional interaction could be applied.

Posturing created with high level controls showed some good results which exhibited many of the subtleties described in body language and expressive movement theory. The subtleties I believe are an important factor in achieving the goal of emotional figure animation. It is these which are difficult to define, but easy to notice that they are missing. The use of DEGAS information files allows the character of the model to be expressed through emotional response and high level control definition.

9.4 The Animation System

The animation system is the second part of the key-frame animation process. Implementation in DEGAS has focused on an investigation of methods for further implementation. As such some of the initial goals have not been met in execution, but have been studied from the context of what has been achieved. As with the posturing system discussion will be as a general examination of the animation system and an appraisal of the emotional interaction methods explored.

9.4.1 As A Whole

The goals for the animation system were similar to those for the posturing system, with a concentration on user control and definition, and the need for emotional interaction in the process. The user definition took the approach of hierarchical control, whereby the basic set-up of animation, based on the emotional state and key-frames, could be adjusted further by the animator. Emotional interaction in the process centred on the manipulation and use of Bezier control curves.

Control splines were used because of their visual and practical properties. Changes made to their shape can be defined using standard techniques, and consequences with respect to animation effects can be easily understood. The use of Bezier Curves as control splines were chosen for their adaptability and ease of definition and use. Investigation of other spline techniques was carried out, and adaptation of the system to a different spline method remains a possibility. Control spline definition also takes into account the use of traditional animation and artistic techniques, as with the posturing system. These were explored as a method for enhancing and reinforcing an animation with the emphasis on emotional effects.

The basic system created does allow for investigation of emotional animation techniques and interaction, but as with the posturing system, can be cumbersome to use. The inclusion of triple key-frame definition in addition to the standard two key-frame process reduces some of the problems. Creation of longer, consistent animation is still a difficult task.

9.4.2 Emotional Interaction

Investigation of emotional interaction techniques has focused on four main areas. The initial definition of emotional effect based on psychological theories of body language and emotional expression. The application of these theories to control spline manipulation, and the application of mixed emotional states to the control spline method. Finally the use of traditional animation techniques to enhance emotional expression through movement.

The definition of emotional effect in movement has been a difficult process and has been kept at a basic level for investigative purposes. By defining the basic emotions in terms of control spline shape and effect the further theories of weighting and mixing could be investigated. The emotional interaction has been broken down into basic shape effects at key areas in the control spline. The resulting restriction of control splines to five equally spaced main points also allowed for important possibilities in the addition and weighting processes. This was required for the application of emotional interaction to the emotional state, and the definition of complex emotions. Two methods were put forward for emotional interaction with respect to complex, mixed emotions, each with advantages and disadvantages. The method which involved weighted addition of basic control splines allowed for greater flexibility in basic emotion control spline manipulation.

The use of traditional techniques in the animation system was examined as an extension of those methods used in the posturing system and of motion specific techniques, such as the use of timing. Discussion centred on their use in enhancing emotional effect and demonstrated how these effects could work within control spline definition.

As it stands the animation system is an adequate test bed for further development in this area. It provides the tools for creation of simple emotional movement with easy adaptation for testing purposes. There is still a lot of work in this area, most notably in definition of emotional effect, where sampled data would be used. The definition of emotional effect on movement is more difficult than that of posturing because of the dynamic elements. Thus the system could be used to examine these effects further by analysis of sampled data.

9.5 Concluding Remarks

I feel DEGAS has gone a significant way towards understanding the problem of natural figure movement. The general approach to the problem of natural figure animation has been that the factor missing from previous models has been emotion. That emotional movement is natural movement. Instead of trying to build emotion into an existing model the approach has been to examine the effect of emotion on posturing and motion almost exclusively, in an attempt to gain a better understanding of the issues involved.

In addition to an examination of emotional effects the limitation of current psychological theory has been taken into account through the investigation of traditional animation techniques. Through life drawing classes I have learned that an artist can capture the essence of a posture and even movement in a few brush strokes or lines. The basic nature of a pose can be broken down into simple elements, but quantification of those elements is where the difficulty lies.

The thesis hypothesis that emotional qualification will give more realistic animation, with fewer postures and a reduced skill requirement has been shown though examples. Complex movement which would normally have required many key-frames or postures to be set by an animator can be achieved with fewer postures. The use of emotional interaction can also be used to automate some characterisation. These methods combine to result in a reduced skill requirement for the animator.

The fact that human recognition of natural movement is so advanced, through a lifetime of experience, makes the problem more difficult. This is the reason why, until greater understanding is achieved, human involvement in the animation process is needed. It is to be hoped that through systems such as DEGAS the greater understanding can be achieved.

Appendices

Appendix A DEGAS File Structure

This appendix gives information on the order of data in the DEGAS information file, supplementary to the discussion and layout of definitions given in Section 5.5 and throughout Chapter 6. This is detailed in the figure A.1. All lines beginning with a '#' sign are ignored as commenting between main definitions.

```
# Opening general comments - Can be used to list joint rotation
# numbering details
...
# Functions [Low Level] :-
# Extra commenting can be used to give order of low-level weights
...
<actual low level weighting>
...
# Functions [High Level] :-
# Info in format
# [Number of joints affected]
# [Joint] [weight of effect] [emotional weights]
...
# Lean F     [no emotional weighting]
# Turn T     [no emotional weighting]
# Side P     [no emotional weighting]
...
# High level control functions defined as above in order>
# StanceOC
# StanceFB
# User 1
# User 2
# User 3
# User 4
# Lower Back
# Raise Back
# Lower Head
# Raise Head
# Shrug
# Negative Shrug
# Join Arms
# Join Legs
# Lean Legs
# Raise Leg Left
# Raise Leg Right
# Raise Foot Left
# Raise Foot Right
# Tip Toes
# Turn Toward
# Look At
# Point At LA
# Point At RA
# Point At BA
# Point At Legs
...
# Constraint Info
...
# Connection Info
...
```

Figure A.1 DEGAS Information File Definition Order

Appendix B Inventor Figure File Structure

The Inventor model files used with DEGAS require certain named nodes to be present for searching and operation purposes. The structure of the figure has already been covered in Section 4.2, this appendix details the node names required and further conventions regarding initial posturing and naming of non-essential nodes. These ensure compatible use of high level control functions and general posturing.

The figure should be defined around the point (0.0 ,0.0, 0.0) with a floor node also centred around this point. The figure is automatically adjusted to stand on the floor once loaded using the Move-to-Floor control function. There are two standard Inventor manipulators used by DEGAS. The first, a *DragPointDragger,* named *myTranslationDragger,* is used for directed control functions. The second, a *TransformBoxDragger,* named *WholeBodyDrag,* is used for global translation and rotation adjustment. The global variables require three nodes, a *Translation* named *WholeBodyTrans*, a *Rotation* named *WholeBodyRot* and a *RotationXYZ* named *WholeBodyLLRot.* The last of which is used exclusively by the Lean Legs control function to maintain its independence from the standard *WholeBodyRot.*

Rotations defining the posture of the figure which are adjustable through control functions are all defined as *RotationXYZ* nodes. There should be a 54 rotations named as detailed in figure B.1. All references to *Left* joints should also be repeated for *Right* joints. For standard figure posturing, those which define the normal posture of the figure, rotations should be named the same as the node they represent followed by the word *Standard.* For example standard left elbow flexion should be named *LeftElbowRotFlexStandard.* They should be inserted in the scene graph next to and preceding the relevant node. As detailed previously the order of application for rotations is twisting, flexion then pivoting. Thus in the scene graph they will be pivoting, flexion and twisting from left to right where applicable.

There are also 23 standard object nodes which are used or could be used by DEGAS control functions for scene graph searching purposes. These are detailed in figure B.2. Again all references to *Left* nodes should be repeated for *Right* nodes. Each should be positioned before the relevant rotations at that point. This ensures the correct transformation matrices are calculated in directed control functions.

BackRot1Pivot	*BackRot1Flex*	*BackRot1Twist*
BackRot2Pivot	*BackRot2Flex*	*BackRot2Twist*
BackRot3Pivot	*BackRot3Flex*	*BackRot3Twist*
BackRot4Pivot	*BackRot4Flex*	*BackRot4Twist*
NeckRot1Pivot	*NeckRot1Flex*	*NeckRot1Twist*
NeckRot2Pivot	*NeckRot2Flex*	*NeckRot2Twist*

LeftAandSRotPivot	*LeftAandSRotFlex*	
LeftMidShoulderRotPivot	*LeftMidShoulderRotFlex*	
LeftArmRotPivot	*LeftArmRotFlex*	*LeftArmRotTwist*
LeftElbowRotFlex	*LeftElbowRotTwist*	
LeftWristRotPivot	*LeftWristRotFlex*	
LeftHipRotFlex		
LeftLegRotPivot Rotation	*LeftLegRotFlex*	*LeftLegRotTwist*
LeftKneeRotFlex		
LeftAnkleRotFlex	*LeftAnkleRotTwist*	

Figure B.1 Standard Rotations in DEGAS Inventor Models

MidPelvis	*Back2*	*Back3*	*Back4*
Neck1	*Neck2*	*Head*	
LeftMidShoulder			
LeftArm	*LeftElbow*	*LeftWrist*	
LeftLeg	*LeftKnee*	*LeftAnkle*	*LeftFoot*

Figure B.2 Standard Object Nodes in DEGAS Inventor Models

Appendix C DEGAS Program File Structure

This appendix details the program files of DEGAS and describes the function of some of the routines used. The system is constructed of five C++ source files each with an associated header file, see figure C.1.

Header Files	**C++ Files**
epincludes.h	*mainep.c++*
constructs.h	*constructs.c++*
updates.h	*updates.c++*
animation.h	*animation.c++*
bitsnbobs.h	*bitsnbobs.c++*

Figure C.1 DEGAS Program source files

C.1 Main Header File *epincludes.h*

The main header file *epincludes.h* is distinct in that it contains the structure definitions for DEGAS and so more explanation is required. The file contains the standard includes, definitions and structures used by DEGAS. The most important structure used by DEGAS is the *progStruct.* This structure contains five sections of information detailing Postures, DEGAS definitions, Open Inventor definitions, Animation information and miscellaneous definitions and variables. These are detailed in figure C2.

The posture information contains pointers to four posture structures. One for each of the three postures which can be set, and a fourth temporary posture for editing purposes. A posture structure contains all the essential values which are specific to, and define, a DEGAS posture. It includes information on low level control values, high level control function values, and global translation and rotation values. It also contains a structure detailing the emotional state relating to the posture.

The DEGAS definitions contain information taken from the DEGAS definition file. This includes structures containing information on high level function interaction and constraint information. These definitions are model specific and control how the model reacts to emotional and posturing input.

The Open Inventor information contains basic Inventor definitions and pointers used by DEGAS. The most important of these is the pointer to the root node of the Inventor scene graph, the geometric model definition. This is used to display the figure using standard Inventor viewing techniques. It is also used in searches of the scene graph in order to obtain information and update values of nodes. There is also a SoTimerSensor, this is an Inventor scene object which is activated at regular definable intervals. With this a program callback function can be called with specific timing, in this case every 1/30th of a second. The restriction on this sensor is that it is also controlled by the timing of the main Inventor loop. So if the Inventor loop is not processed every 1/30th of a second then the sensor will not be activated. The main cause of delays in the Inventor loop is the rendering time. This can be countered by ensuring the hardware is powerful enough to handle the model complexity, or by using a simpler Inventor model. This sensor is used when spooling an animation to a file. Every 1/30th of a second a function is called which outputs the current joint angles and figure positional information to a file. This information can then be used by other programs to play-back animation sequences.

```
// posture information
        Posture *temppost;              // temporary posture
        Posture *posture1;              // posture #1
        Posture *posture2;              // posture #2
        Posture *posture3;              // posture #2
// DEGAS definition file information
        Degas degas;                    // Degas info
        Constraints constraints;        // Joint constraints
// Open Inventor information
        SoNode *root;                   // pointer to the root node in
                                        // Inventor scene graph
        SoTimerSensor *myTS;            // Timer Sensor used for spool
        SbViewportRegion vpReg;         // Viewport
// Animation information
        fstream InStream;               // In and Out streams
        fstream OutStream;              // (used for spooling)
        int changed;                    // Posture changed flag
                                        // (also used for spooling)
        DAstruct daS;                   // Drawing area information

// Miscellaneous information
        int posediting;                 // Posture currently editing
        int views;                      // Number of views
```

Figure C.2 Main DEGAS data structure, *progStruct*

The animation information contains variables and structures associated with the animation and spooling part of DEGAS. This includes file stream information for file handling, and a flag which gets set when a posture is updated or changed. The flag is used for spooling purposes and allows the loading of postures without the changes being spooled to a file until the animation is put in motion. The final structure in this section is the *DAstruct* which contains information on spline definition, use, and display. Splines are displayed and edited in a Motif drawing area. A drawing area is a widget which can be written to and read from, in order to display and manipulate 2d information. The *DAstruct* contains the spline information such as the database and editing values. It also has animation information concerning Inventor sensors used to time the animation, flags, and animation joint values.

The miscellaneous information section holds various global values pertaining to DEGAS. This includes which posture is currently being edited and information on the number of views being used.

C.2 The Main Program File *mainep.c++*

This program file contains the main loop and heart of DEGAS. It handles the initialisation and management of the system. It also contains specific routines for the set-up of the viewing window, including picking information and menu configuration. The picking information details actions taken when the mouse pointer is used in the viewing window. This is useful as a short-cut to select part of the figure to adjust when posturing.

C.3 Motif Management Files *constructs.c++* and *constructs.h*

These large files contain the Motif widget and window construction details. Each window, button, menu and other widgets used by DEGAS has to be defined in terms of position and use. For buttons, menus and sliders callback functions are defined and attached to events. This means when an event such as a button press or slider movement occurs then the callback function list is processed. The design aspect of DEGAS in this area was a lengthy process.

C.4 Posturing Control Files *updates.c++* and *updates.h*

This file controls the updates to the figure in the posturing system of DEGAS. The functions contained are listed below in figure C.3, and are structured in a hierarchical way. For example the updateArmGroup function calls updateLeftArmGroup and updateRightArmGroup. The functions are based on areas of the figure so interaction with the high level control functions is simpler. The majority of high level control functions are restricted in the areas which they can control. Thus the functions which are called by a particular high level control function are dependent on this. In this way updates to the figure and re-interpretation of the high level control functions after a user input is less costly in processing time.

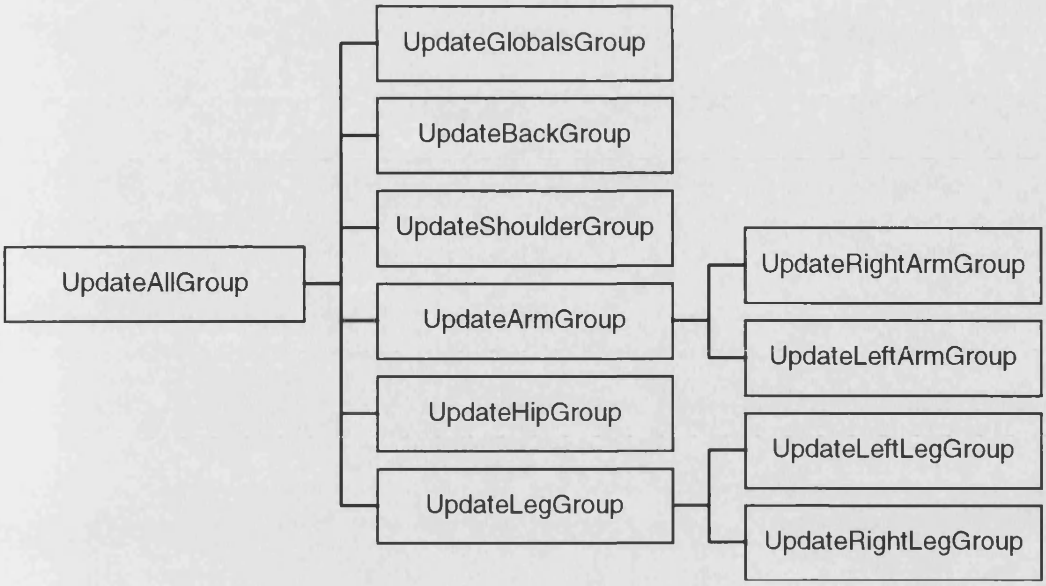


Figure C.3 Update Functions

C.5 Animation Control Files *animation.c++* and *animation.h*

The animation program files contain routines which control the set-up and implementation of animation. From the spline adjustment and definition, to the control of the animation itself. These are detailed in table C.1. The functions have been separated into six sections, Input / Output, Drawing, Spline Update, Spline Database, List Maintenance and Animation Control.

Input / Output and Display functions handle basic maintenance and input to the drawing area window in which splines are edited. Specifically they manage refresh of the drawing area when required, menu set up, and basic control of mouse input to the drawing area itself. There are several actions which can be taken on receiving a mouse button press in the drawing area. A point on a spline can be manipulated or moved. The function *inputCB* controls what the input is trying to achieve and acts upon it.

The Drawing functions handle basic drawing of lines and objects on the drawing area. This includes functions for drawing basic primitives such as points, crosses, squares and styled lines.

The Spline update functions handle specific spline adjustment input. Obtaining the position of the mouse within the drawing area and updating of the spline data to account for the adjustments.

The List update and maintenance functions are used to manage the spline structures. The points in the splines are stored in a linked list, and the functions here are used to initialise, clear, add to and remove from these lists. The *cleanCB* routine is used when exiting DEGAS to free the memory allocated to the splines.

Routine Section	Routines
Input / Output and Display Functions	*fileMenuPick, presetMenuPick, exposeCB, inputCB, andCB*
Drawing Functions	*drawPts, drawPtSquare, drawX, drawCoordLine*
Spline Update Functions	*getHitlp, updateCoeffs, computeCoeffs*
Spline Database Maintenance Functions	*updateSplinedata, updateIndexdata, copySpline, setSplineCB, upSplineCB, downSplineCB, addSpline, InitPreset2, InitPreset3, InitPreset4*
List Update and Maintenance Functions	*initList, addItem, removeItem, clearQueue, cleanCB*
Animation Control Functions	*animCB, initRots, setupAnim, timeChange, solveCubic*

Table C.1 Animation Routines

The Spline Database maintenance functions manage the array of splines used by DEGAS. They handle updates to the database, and navigation and retrieval from it. There are also important functions which copy, paste and add splines within the database. The *InitPreset* functions are used to set basic pre-defined splines.

The Animation Control functions are the heart of the animation system. These control set-up, updates, time and management of a defined animation. The routines *initRots* and *setupAnim* control the initialisation of the animation. Consequently *timeChange* and *animCB* control actions and updates once the animation is in motion. The routine *solveCubic* is used to find solutions to the control splines at a given time interval.

C.6 Extra Function Files *bitsnbobs.c++* and *bitsnbobs.h*

The bitsnbobs files contain a large number of routines related to several smaller areas of posturing, such as set-up, updates and data management. These are detailed in table C.2.

The first section contains set-up routines for the posturing system. The routine *manipSetup* is used to initialise the Inventor manipulator used for global translation and rotation. It also attaches a callback function to the manipulator which is used to update the figure when the manipulator is adjusted. The second routine, *setInitialConstraints*, is used to initialise the constraint data taken from the DEGAS information file.

The Change callbacks are routines which are attached to buttons in the posturing system which cause a direct change to the posture of the figure. Most are not considered control functions, as they simply reset others or are associated with DEGAS functionality. The *stickFloorCB* and *moveToFloor* routines are used to auto-adjust the translation of the figure during posturing or animation.

Routine Section	Routines
Set-Up Routines	*manipSetup, setInitialConstraints*
Change Callbacks	*globalChangeCB, stickFloorCB, moveToFloor, straightBack, straightLean, straightSide, straightTurn, setPost, changePos*
Reset Routines	*resetPost, resetGlobalPost, resetScale, resetJoint, resetLeanPost, resetTurnPost, resetSidePost, resetUpdateBack*
Update Callbacks	*updateGlobalManip, updateGlobalSliders, updateSliders, updateEmotionSliders, updateLeanSliders, updateSideSliders, updateTwistSliders, updateArmSliders, updateLegSliders, updateBack, updateText, updateConstraints, updateConstdata*
Data Management and Manipulation Routines	*transferPosture, transferJoint, fieldSet*
File Access Routines	*fileOpen, fileSave, fileOpenDegas, degasFile*
Spooling Routines	*shedSpool, unshedSpool, spoolTCB, noSpool*
Miscellaneous Routines	*showPopy, hidePopy*

Table C.3 Main Bitsnbobs Routines

The Reset routines are simply convenience functions to reset all, or part, of the posture. They are commonly used by the buttons attached to the Change callbacks detailed above.

The Update routines are used to set the sliders and manipulators during the normal running of DEGAS. When the animator changes between set postures, or loads a new posture, then the new values must be carried through to the sliders and manipulators.

The Data management routines control data flow and updates. When a posture is loaded, or the animator switches between set postures, then the temporary posture structure needs updating. This is handled by the *transferPosture* routine, which in turn uses the *transferJoint* routine. The *fieldSet* routine is used for converting text into numeric values. This is needed where the user is allowed to enter data in text fields, such as in the constraint window.

The File Access routines control the reading in and output of data files. This includes posture and DEGAS information files.

Spooling routines handle the spooling of animation information to a file. This involves the scheduling and unscheduling of the spooling time sensor discussed previously. The *spoolTCB* routine is the callback associated with the time sensor, and it is this which is called when the time sensor is activated. The *noSpool* routine is to stop the spooling of posture change when loading and setting new postures.

Finally there are two miscellaneous routines, *showPopy* and *hidePopy.* These show and hide the various pop-up windows when needed. These routines are required as callbacks to be attached to buttons in the window hierarchy. For example, when the Animation button is pressed in the main Control Panel, then the *showPopy* routine is used to bring up the Animation window.

References

[1]. N I Badler (1987) Articulated Figure Animation: Introduction, IEEE Computer Graphics and Applications, Vol. 7, No. 6, pp.10-11.

[2]. M Girard (1987) Interactive Design of 3D Computer-Animated Legged Animal Motion, IEEE Computer Graphics and Applications, Vol. 7, No. 6, pp.39-51.

[3]. N I Badler, K Manoochehri, G Walters (1987) Articulated Figure Positioning by Multiple Constraints, IEEE Computer Graphics and Applications, Vol. 7, No. 6, pp.28-38.

[4]. J Wilhelms (1987) Using Dynamic Analysis for Realistic Animation of Articulated Bodies, IEEE Computer Graphics and Applications, Vol. 7, No. 6, pp.12-27.

[5]. W W Armstrong, M Green, R Lake (1987) Near-Real-Time Control of Human Figure Models, IEEE Computer Graphics and Applications, Vol. 7, No. 6, pp.52-61.

[6]. S N Steketee, N I Badler (1985) Parametric Key-frame Interpolation Incorporating Kinetic Adjustment and Phrasing Control, ACM SIGGRAPH '85 Proceedings, Vol. 19, No. 3, pp.255-262.

[7]. G Monheit, N I Badler (1991) A Kinematic Model of the Human Spine and Torso, IEEE Computer Graphics and Applications, March 1991, pp.29-38.

[8]. D Thalmann (1993) Human Modelling and Animation, Eurographics '93 State of the Art Reports.

[9]. R Boulic, N Magnenat Thalmann, D Thalmann (1990), A Global Human Walking Madel with Real-Time Kinematic Personification, The Visual Computer 1990, Vol. 6, pp.344-358.

[10]. R Boulic, D Thalmann (1992), Combined Direct and Inverse Kinematic Control for Articulated Figure Motion Editing, Computer Graphics Forum, Vol. 11, No. 4, pp.189-202.

[11]. N Magnenat-Thalmann, D Thalmann (1991) Complex Models for Animating Synthetic Actors, IEEE CG&A Sept 1991, pp.32-44.

[12]. Unuma M, Takeuchi R (1991) Generation of Human Motion with Emotion, Computer Animation '91, pp.77-88.

[13]. Unuma M, Anjou K, Takeuchi R (1995) Fourier Principles For Emotion-Based Human Figure Animation, SIGGRAPH '95 Proceedings, pp. 91-96.

[14]. A J Stewart, J F Cremer, (1992) Beyond Keyframing: An Algorithmic Approach to Animation, Graphics Interface '92, pp.273-281.

[15]. J K Hodgins, P K Sweeney, D G Lawrence (1992) Generating Natural-looking Motion for Computer Animation, Graphics Interface '92, pp.265-272.

[16]. J Wilhelms, B Barsky (1985) Using Dynamic Analysis to Animate Articulated Bodies such as Humans and Robots, Graphics Interface '85, pp.97-104.

[17]. J Wilhelms (1991) Dynamic Experiences, Making Them Move, Edited by N Badler, B Barsky, D Zeltzer, Publisher Morgan Kaufmann.

[18]. M Green (1991) Using Dynamics in Computer Animation : Control and Solution Issues, Making Them Move, Edited by N Badler, B Barsky, D Zeltzer, Publisher Morgan Kaufmann.

[19]. J Cassell, C Pelachaud, N Badler, M Steedman, B Archon, T Becket, B Douville, S Prevost, M Stone (1994) Animated Conversation, ACM Computer Graphics 1994.

[20]. L S Brotman, A N Netravali (1988) Motion Interpolation by Optimal Control, ACM SIGGRAPH '88 Proceedings , pp.309-315.

[21]. A Witkin, M Kass (1988) Spacetime Constraints, ACM SIGGRAPH '88, pp.159-168.

[22]. M van de Panne, E Fiume (1993) Sensor-Actuator Networks, ACM SIGGRAPH '93 Proceedings, pp.335-342.

[23]. J T Ngo, J Marks, (1993) Spacetime Constraints Revisited, ACM SIGGRAPH '93 Proceedings, pp.335-342.

[24]. Z Liu, S J Gortler, M F Cohen (1994) Hierarchical Spacetime Control, ACM SIGGRAPH '94 Proceedings, pp.35-42.

[25]. A Bruderlin, L Williams (1995) Motion Signal Processing, ACM SIGGRAPH '95 Proceedings, pp.97-104.

[26]. A Daldegan, P Kalra, N Magnenat Thalmann (1995) An Emotion-Based Tool for Simulating Virtual Actor's Facial Expressive Behaviour, XV International Conference of the Chilean Computer Science Society Proceedings, pp.123-136.

[27]. M Patel (1991) Making FACES The Facial Animation Construction and Editing System, Thesis, University of Bath, UK.

[28]. W S Reilly, J Bates (1992) Building Emotional Agents, Technical Report CMU-CS-92-143, School of Computer Science, Carnegie Mellon University, Pittsburgh.

[29]. J Lasseter (1987) Principles of Traditional Animation Applied to 3D Computer Animation, ACM Computer Graphics Vol 21, No 4, pp.35-44.

[30]. X Pueyo, D Tost (1988) A Survey of Computer Animation, Computer Graphics Forum 1988 Vol. 7 pp.281-300.

[31]. T Schiphorst, T Calvert, C Lee, C Welman, S Gaudet (1990) Tools for Interaction with the Creative Process of Composition, ACM CHI '90 Proceedings, pp.167-174

[32]. A Bruderlin (1996) Supporting the Creative Process of Human Figure Animation, 2nd Symposium on Creativity and Cognition 1996 Proceedings, pp.85-94.

[33]. K Amaya, A Bruderlin, T Calvert (1996) Emotion from Motion, Graphics Interface '96 Proceedings.

[34]. J Sato, T Miyasato (1997) Autonomous Behaviour Control of Virtual Actors Based on the AIR Model, Computer Animation '97 Proceedings, pp.113-118.

[35]. D Densley, P J Willis (1997) Emotional Posturing: A Method Towards Achieving Emotional Figure Animation, Computer Animation '97 Proceedings, pp8-14.

[36]. N I Badler, B A Barskey, D Zeltzer (Eds.) (1991) Making Them Move, Publisher Morgan Kaufmann.

[37]. N I Badler, C B Phillips, B L Webber (1993) Simulating Humans, Publisher Oxford University Press.

[38]. N Magnenat Thalmann, D Thalmann (Eds.) (1989) State-of the Art in Computer Animation, Publisher Springer-Verlag.

[39]. N Magnenat Thalmann, D Thalmann (1990) Synthetic Actors in Computer Generated 3D Films, Publisher Springer-Verlag.

[40]. K Oatley, J M Jenkins, (1996) Understanding Emotions, Publisher Blackwell.

[41]. Izard CE (1977) Human Emotion, Publisher New York: Plenum.

[42]. Collier, G (1985) Emotional Expression, Publisher Lawrence Erlbaum Associates, Inc.

[43]. Ekman P, Friesen WV (1967) Head and Body Cues in the Judgement of Emotion: A Reformulation, Perceptual an Motor Skills, Vol 24, pp.711-24.

[44]. M Argyle (1975) Bodily Communication, Publisher Methuen and Co.

[45]. P E Bull (1987) Posture and Gesture, Publisher Pergamon.

[46]. A Pease (1981) Body Language, Publisher Sheldon Press.

[47]. D Lambert (1996) Body Language, Publisher Harper Collins.

[48]. N H Frijda (1977) The Emotions, Publisher Cambridge University Press.

[49]. R Arnheim (1967) Art and Visual Perception, Publisher Faber.

[50]. J Itten (1970) The Elements of Colour, Publisher Van Nostrand Reinhold

[51]. H Varley (Ed.) (1980) Colour, Publisher Marshall Editions

[52]. J Wernecke (1994) The Inventor Mentor, Publisher Addison-Wesley

[53]. A Nye (Ed.) (1992) Xlib Reference Manual, Publisher O'Reilly and Associates Inc.

[54]. Open Software Foundation (1991) OSF/Motif Programmer's Guide, Publisher Prentice Hall

[55]. The Chambers Dictionary (1993) Chambers Harrap Publishers Ltd.

[56]. N I Badler (1982) Modelling the Human Body for Animation, IEEE Computer Graphics and Applications, November.